LIBRARY

18

FEB 19 1929

Vol. XII, No. 1 *PSYCHOLOGICAL REVIEW PUBLICATIONS* FEBRUARY, 1929

Journal of Experimental Psychology

EDITED BY

MADISON BENTLEY, CORNELL UNIVERSITY

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)
WALTER S. HUNTER, CLARK UNIVERSITY (*Index*)
HERBERT S. LANGFELD, PRINCETON UNIVERSITY, Business Editor

CONTENTS

The Reproduction of Visually Perceived Forms: JAMES J. GIBSON... 1

Protracted Passive Oscillation and Intermittent Rotation of the Body; Variability in Perception and Reaction: ROLAND C. TRAVIS.... 40

Primacy, Recency, Frequency and Vividness: ARTHUR JERSILD..... 58

The Effect of Overlearning on Retention: WM. C. F. KRUEGER..... 71

Identification of Monocular Functions:
ERNST THELIN AND ESTHER ROYAL ALTMAN 79

PUBLISHED BI-MONTHLY
FOR THE AMERICAN PSYCHOLOGICAL ASSOCIATION
BY THE PSYCHOLOGICAL REVIEW COMPANY
PRINCE AND LEMON STS., LANCASTER, PA.
AND PRINCETON, N. J.

Entered as second-class matter, July 1, 1920, at the post-office at Lancaster, Pa.

Psychological Review Publications

of the American Psychological Association

EDITED BY

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
MADISON BENTLEY, CORNELL UNIVERSITY (*J. of Exp. Psych.*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)
WALTER S. HUNTER, CLARK UNIVERSITY (*Index*)
HERBERT S. LANGFELD, PRINCETON UNIVERSITY, Business Editor

WITH THE CO-OPERATION OF
MANY DISTINGUISHED PSYCHOLOGISTS

PSYCHOLOGICAL REVIEW

containing original contributions only, appears bimonthly, January, March, May, July, September, and November, the six numbers comprising a volume of about 480 pages.

PSYCHOLOGICAL BULLETIN

containing critical reviews of books and articles, psychological news and notes, university notices, and announcements, appears monthly, the annual volume comprising about 720 pages. Special issues of the BULLETIN consist of general reviews of recent work in some department of psychology.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

containing original contributions of an experimental character, appears bimonthly, February, April, June, August, October, and December, the six numbers comprising a volume of about 500 pages.

PSYCHOLOGICAL INDEX

is a compendious bibliography of books, monographs, and articles upon psychological and cognate topics that have appeared during the year. The INDEX is issued annually in June, and may be subscribed for in connection with the periodicals above, or purchased separately.

PSYCHOLOGICAL MONOGRAPHS

consist of longer researches or treatises or collections of laboratory studies which it is important to publish promptly and as units. The price of single numbers varies according to their size. The MONOGRAPHS appear at irregular intervals and are gathered into volumes of about 500 pages.

ANNUAL SUBSCRIPTION RATES

Review: $5.50 (Foreign, $5.75)
Journal: $6.00 (Foreign, $6.25)
Bulletin: $6.00 (Foreign, $6.25)
Monographs: $6.00 per volume (Foreign, $6.30)
Psychological Index: $4.00

Current Numbers: Review or Journal, $1.00; Bulletin, $.60

Review and Bulletin: $10.00 (Foreign, $10.50)
Journal and Bulletin: $11.00 (Foreign, $11.50)
Review and Journal: $10.00 (Foreign, $10.50)
Review, Bulletin, and Journal, $15.00 (Foreign, $15.75)
Review, Bulletin, Journal, and Index: $18.00 (Foreign $18.75)

Subscriptions, orders, and business communications may be sent direct to the

PSYCHOLOGICAL REVIEW COMPANY
PRINCETON, N. J. OFFICE

Science Lib
Wash

Journal of
Experimental Psychology

VOL. XII., No. 1 FEBRUARY, 1929

THE REPRODUCTION OF VISUALLY PERCEIVED FORMS

BY JAMES J. GIBSON

Princeton University

INTRODUCTION

The object of this investigation was to observe the ways in which the reproduction of visually perceived forms varies from the original stimuli. We undertook first to compare perceived forms with the same forms as the observer subsequently draws them, and secondly to relate the difference to the observer's reports upon the nature of the perception. Since the differences are caused by factors in the processes of perceiving, remembering and reproducing, a study of these differences between the perceived and reproduced figures should yield information upon the factors.

The problem was suggested by F. Wulf's study of ideational change which appeared in 1922.[1] Wulf set out to investigate the changes in memory images which may occur with the lapse of time.

Wulf used various visual forms drawn with ink on white cards. The form was exposed on a table by uncovering the card for a period of from 5 to 10 sec, depending on the complexity of the form. After 30 sec (during which O was requested not to think of the exposed figure) O was required to reproduce the figure on paper as accurately as possible and to give a report of his experiences during reproduction, including his imagery, his estimation of the correspondence of the reproduction with the stimulus figure, and any word or meaning which had attached itself to the form. On the next day O was again required to reproduce the figure and to report. A week later the observer was shown a drawing of a small part of the original form which he was instructed to complete. This 'part-stimulus' (*Teilvorlage*) was used only as an aid to O in recalling the figure. O was left in doubt as to whether or not it was exactly congruent with the

[1] F. Wulf, Beiträge zur Psychologie der Gestalt; VI. Ueber die Veränderung von Vorstellungen (Gedächtnis und Gestalt), *Psychol. Forsch.*, 1922, 1, 333–373.

corresponding part of the original. In other words, the original figure was presented only once on the first day, and the 'part-stimulus' was later given as a cue to its reproduction. The Os always remembered the figure upon seeing the 'part-stimulus'; although sometimes they changed this to accord better with what they remembered the form to be. In some cases (Wulf does not state how many) this reproduction from the 'part-stimulus' was repeated after a period of 2–8 weeks. Twenty-six figures were presented individually to six observers. The procedure outlined above, however, was not strictly adhered to for all Os. The total number of reproductions was only about 400.

Wulf concludes that the reproductions show a change either towards *sharpening* (*Präzisierung*) or *levelling* (*Nivellierung*). *Sharpening* Wulf defines as the exaggeration or emphasis of a characteristic or peculiarity of the presented figure; *levelling* as the omission, toning down or weakening of a characteristic. He found, *e.g.* in a preliminary experiment that where there were presented two curved lines side by side and convex in the same direction, one line having a somewhat sharper degree of curvature than the other, so that the two lines were closer together at the ends than in the middle, the line of lesser curvature was changed so that it curved more and became parallel to the other. This reproduction was unusual in that it showed both sharpening and levelling. There was sharpening with respect to one part of the figure, *i.e.* one characteristic (the curvature of one line) was exaggerated; but there was also levelling with respect to the figure as a whole in that another characteristic (the difference in curvature of the two lines) was eliminated. Had reproduction increased the difference in curvature of the two lines, this also would have constituted sharpening.

These two kinds of change are regarded by Wulf as two possible directions (*Richtungen*) which the forms may take in the course of memory. The change (whether sharpening or levelling) is for him *continuous*, *i.e.* the change becomes progressively larger with each subsequent reproduction, and the direction of either change remains the same.[2]

[2] "With the exception of 8 cases (of which 6 resulted either in no, or entirely strange, reproductions) the comparison of reproductions with stimulus figures shows a constant, clear variation either in the direction of sharpening or levelling, and the comparison of different reproductions of the same figure coming at different times shows that the changes overwhelmingly follow a definite direction, which as a rule is plainly indicated in the first reproduction." Wulf, p. 340.

Sharpening and levelling are, however, only the most general classes into which the changes may fall. This is only a primary classification. Wulf distinguishes three specific kinds of change which cause sharpening or levelling;—three ways in which sharpening and levelling may occur. The first kind he calls *normalizing* (*Normalizierung*), *i.e.* a change (presumably in the reproductions) in the direction of a familiar object. If the presented object is apprehended as a 'bridge with pillars,' the reproduction shows a modification towards the object. As a rule, the modification increases in subsequent reproductions. Wulf's explanation is that the normal or conceptual form [3] of a bridge which was aroused during the perception becomes more firmly established (*sich durchsetzt*) with each succeeding reproduction. The change is still, from a logical standpoint, either sharpening or levelling. It is also, however, and more specifically, a change in the direction of a familiar object.

The second kind of change is called '*emphasizing*' (*Pointierung*). The observer notes particularly some characteristic of the stimulus figure, some peculiarity which attracts his attention, and as a result this characteristic or peculiarity is exaggerated in the reproduction. Here, Wulf states, the change is not determined by the normal structure (as in *normalizing*), but by some variation from the norm particularly noticed by the observer. If one part of a figure is noted as smaller than another, then this relationship is increased in the reproduction.

The third kind of change occurs where the mode of apprehending the figure is not a factor in causing the change, but where the cause lies in the attributes of the form (*Struktur*) itself (352). Accordingly it is characterized as a *structurally conditioned change* (*struktive Veränderung*). The direction of the change is determined quite independently of *normalizing* or *emphasizing;* it is due to the nature of the *structure*. A

[3] 'Form' is here used as a translation of '*Struktur*,' a word very frequently used by Wulf with the apparent meaning of *general image* or *concept*. It is defined as "first a compact, static or dynamic, non-summative experience-cohesion (*Erlebniszusammenhang*) and next the physiological correlate belonging to it" (350). Hereafter '*Struktur*' will be translated either as 'form' or 'structure.'

form, *e.g.* tends to be drawn symmetrical even where a normalizing apprehension works in the direction of asymmetry. Here the *structurally conditioned change* is the stronger of the two (352, 356).

In addition to the classifications already described, Wulf distinguishes two types of perception, which he arrives at in the following way. The characteristics of the first reproduction, *i.e.* the changes which it exhibits, are determined in large measure by the original apprehension (*Auffassung*) of the form, which is different for different observers. The same form may be grasped as 'two triangles,' as 'letter W' or as 'mountains.' The apprehension, then, expresses the character of the perception as dependent on the observer. Wulf defines the word *Auffassung* as "The phenomenal data with respect to the conditions within the subject which contribute towards determining the data" (347). These 'apprehensions' he divides into two classes, into two general ways of apprehending forms or two types of perception. The one type is the apprehension of forms as things or familiar objects; the other is the apprehension of forms as drawings or geometrical arrangements. It is not true to say that one type goes beyond what is given, perceives *more* than the mere stimulus or *transforms* the stimulus, while the other does not. In both types a name is given to the form, and in both the form is related to objects. The difference lies in the *kind* of object. The first type involves familiar, substantial objects, whereas the second involves geometrical objects, figures or figure-parts. Apprehension in the first case might be 'mountains,' in the second 'two triangles.' Since the objects of the first type are more general and 'real' and are not limited to two dimensions, Wulf calls this the *comprehensive type*, and the second the *isolative type*. The three kinds of change described above may be found with either of these two types of perception.

Wulf states that his distinction between these two types of perception is much the same as that made by Katz,[4] who distinguishes *central* and *peripheral types* of visual perception. In the one type, central factors exert more influence in determining the perception; in the other, peripheral factors (Katz, p. 173). In the one, the figure is

[4] D. Katz, Ueber individuelle Verschiedenheiten bei der Auffassung von Figuren, *Zsch. f. Psychol.*, 1913, 65, 161–180.

three-dimensional; in the other, plane. Katz believed that the individual tends to the one or to the other type of perception.

Still earlier Messmer [5] had also made a distinction between two types of perception which in many ways seems to be the source of that made by Wulf and by Katz. Messmer found in experiments with tachistoscopically exposed words that some observers always perceived a complete word, similar to the stimulus word but incorrect, while others correctly perceived *parts* of the stimulus word and gradually pieced them together (202 ff.). The former observers showed fluctuating attention and tended subjectively to transform what was presented; while the latter attended steadily and transformed less. Messmer accordingly called them *subjective* and *objective types*. The relation of this to Katz's *central* and *peripheral* types and to Wulf's *comprehensive* and *isolative* types is evident.

Method of Experimentation [6]

A. Theoretical Considerations. The present investigation undertakes—as we have said—to study the changes which occur in the reproduction of forms, *i.e.* the ways in which reproductions are inexact copies of presented figures. We are concerned with objective differences between the reproductions and the standard stimulus-figure. These variations from the standard figure are taken to be indications of the mental processes occurring between the presentation and the reproduction.

The object of study, then, being these variations or 'errors,' the method of experiment must provide them in the reproductions. Favorable conditions for 'accurate' perception and 'accurate' retention must be limited so that 'correct' reproductions are not the rule. The task of the observer must not, therefore, be made too easy.

Several methods are possible. First, the exposure period may be limited to a fraction of a second. This is a traditional method for the experimental study of perception. Secondly, the exposure may be made under reduced illumination. The stimuli are presented subliminally or just liminally different from the background.[7] Thirdly, the exposure period may be fairly long (one to several seconds); but the reproduction is deferred. This is the method which Wulf used and its purpose is to lengthen the time during which it is necessary to 'retain.' Fourthly, the exposure period may be fairly long, as before, but the stimuli used are complicated patterns which

[5] O. Messmer, Zur Psychologie des Lesens bei Kindern und Erwachsenen, *Arch. f. d. ges. Psychol.*, 1903, 2, 190–298.

[6] The experiments were carried out in the Psychological Laboratory of Princeton University, under the direction of Professor H. S. Langfeld, to whom the writer is deeply indebted.

[7] *E.g.* L. Hempstead, The perception of visual form, *Amer. J. Psychol.*, 1901, 12, 185.

exceed the perceptual span.[8] Fifthly, the exposure period may again be fairly long, but the stimuli are presented serially so that it is necessary to retain not one stimulus but several. This method is used in the present investigation. In defense of it, it may be urged that a series of perceptions coming in a group better approximates the situations of everyday life than does a single isolated perception, and that therefore the conclusions resulting from such a method would better apply to everyday perception than would conclusions based on a method using an isolated presentation.

Whether the changes occur during perception or memory, whether or not change is involved in the process of recognition, and how much change is involved in the process of reproduction, are questions which cannot easily be determined.[9] To the present writer they are not questions of great significance. How is it possible to distinguish, except abstractly, between perception and retention, between retention and recognition, or between recognition and reproduction? It would seem that in reality what goes on between the moments of fixating a visual object and the subsequent reproduction of that object is a continuous and unitary process. Temporal distinctions between earlier and later parts of it, such as 'perception,' 'retention' and 'reproduction' may be convenient and necessary, but they should never make us lose sight of the continuous and uniform nature of the process. As Judd says in his *Studies in perceptual development*, "The tests [*i.e.* Judd's experiments] should not be criticised because they involve memory; it should rather be recognized that all perception involves memory, the memory phase being in general overlooked by any purely analytical method of examining experience."[10]

B. Description of Method. In the experiments of Group I, two series of fairly simple geometrical forms were used. Series A, the 'straight series,' consisted of 14 figures made up of straight lines. Series B, the 'curved' series, consisted of 14 figures made up of curved lines except that in four figures straight-line components were included. In both series 7 of the 14 figures had from two to four breaks or gaps in the contour. (See Charts I and II.) The maximal dimension for any figure was $\frac{7}{8}$ inch.

The figures were exposed in a modified Ranschburg Memory Apparatus.[11] The white cardboard exposure disc was ruled off into 15 sectors and the 14 figures were drawn within these areas on the periphery of the disc. One space was left empty. A new cover was made for the instrument with a circular window $1\frac{1}{4}$ inches in diameter. The old cover was designed for the exposure of words. The mechanism was so modified that the exposure disc rotated with a jerk through an arc of 12 degrees, or just far

[8] *E.g.* C. H. Judd & D. J. Cowling, Studies in perceptual development, *Psychol. Rev. Monog. Suppl.*, 1907 (No. 34), 353.

[9] The distinctions between these processes and an analytic treatment of the changes in a memory image, *i.e.* 'memory illusions,' may be found in Titchener, *A text-book of psychology*, 1924, 396–427. For a fuller treatment of changes in imagery see F. Kuhlmann, On the analysis of the memory consciousness; a study in the mental imagery and memory of meaningless visual forms, *Psychol. Rev.*, 1906, 13, 333–336.

[10] Judd & Cowling, *op. cit.*, 357.

[11] For a diagram and explanation of this apparatus see Titchener, *op. cit.*, 381.

enough to expose a new figure, when the circuit was completed through the electromagnets. Contacts were made on a revolving brass drum driven by a constant-speed motor.

The period of exposure for each figure was approximately 1½ sec. The observer sat at a table on which the apparatus lay. The exposure opening was normally about 1½ feet from O's eyes; although O was allowed to change this distance to suit his convenience. He was instructed simply to look carefully at each figure and at the end of the series to draw as many figures as he remembered in any order he wished.

The experimenter sat by the side of O taking notes on the reproductions as they were made. O was encouraged to comment on his reproductions and to discuss the method used, but this was not always sufficient. Whenever a drawing showed a change from the stimulus figure and information regarding the reproduction was not volunteered, O was questioned. Care was taken, however, not to inform him how his reproduction varied from the original. 'Leading questions' as to the explanation of any such variation were avoided by asking only such questions as "Tell me about this figure" or "What do you remember about this one?" No definite time limit was set for reproduction. O was allowed to continue until he stated that he could not remember any more figures, or until he had not made a drawing for some time. The entire period of reproduction never exceeded 5 or 6 minutes.

It was planned in this first group of experiments to study both the learning of the two series of figures and the subsequent forgetting of them. The Os were to continue seeing and reproducing the forms until they were able to reproduce both series 'correctly.' Then, at intervals thereafter, they would be requested to reproduce the forms from memory. The six Os were designated Br, Ca, Do, Hu, La, and Sch. At the first experimental sitting with a given observer the cardboard disc prepared for Series A ('straight') was put into the apparatus and the figures were exposed in the manner described. O then reproduced as many forms as he could remember. The exposure was repeated, and if by this time the observer still could not reproduce more than 7 figures of the series, it was given a third time. Series B ('curved') was then put into the apparatus and it also was exposed twice and if necessary a third time, with reproduction after each exposure. At the second experimental sitting and at all subsequent sittings, before any figures were exposed the observer was required to draw from memory all of the forms he could remember from the previous sitting. After this preliminary reproduction, first for Series A and then for Series B, the figures were presented and reproduction was made in the same manner as in the first sitting. The sittings were continued (6 to 8) for each O until he could reproduce all the figures of both series.

It was found, however, that the plan of these early experiments, which was first to have the observers learn the forms and to reproduce them correctly and next to study the process of forgetting, could not be fully carried out. In the first place, no definite criterion could be found of having *learned* a figure, since there could be no arbitrary standard of the *correctness* of a reproduction. Absolute correctness would have been complete correspondence of reproduction to stimulus figure; but this never occurred. In the second place it was discovered that each O's reproductions varied from the original forms by certain characteristic changes which tended to become habitual in the later experimental sittings, and which could only partially and with difficulty be eliminated, even with repeated exposures of the pattern figures. Certain modes of apprehension, Wulf's *Auffassungen*, consistently occurred in the perception of many of the forms and conditioned these changes. In fact, when, about 5 weeks after the final exposure, the observers were requested to draw the figures of Series A and B from memory and to give an account of the process of reproduction for each, they

reverted to their characteristic modes of reproducing. A year later the same request was made of the observers and the changes were found to have persisted in those figures which were reproduced.[12] Therefore, we cannot accurately speak of learning or forgetting the forms. The observers perceive and reproduce them in certain ways, and remember them with certain modifications. Learning and forgetting are terms which involve a distinction between 'correct' and 'incorrect.' This distinction is not practicable for the learning material used in these experiments.

After the experiments of Group I had been completed, Group II was undertaken in order to study more specifically the changes appearing in the reproductions and the frequency with which they appeared. The period of exposure for each figure was two sec instead of 1½; but otherwise the method was the same as in Group I. Twenty Os were used. No attempt was made to have the observers 'learn' the figures as was the case in Group I. Each observer was given only one experimental sitting. Series A was presented and reproductions were made. It was then presented a second time to the observer and again the observer drew the figures. Series B was then presented twice in the same manner. There were, thus, four sets of reproductions for each observer. Notes were taken on the reproductions in the same manner as in Group I, except that here, after the experiment was over, the observer could be shown the stimulus figures side by side with his reproductions and could be questioned about the changes which appeared.

Results

Approximately 4,000 reproductions of the 28 figures were secured, together with E's notes taken at the time of reproduction. The reproductions showed, in greater or lesser degree, changes from the stimulus figures. These changes varied from the most insignificant to others so great that the resulting form could only with difficulty be recognized as a copy of the original.[13] On first studying them the changes

[12] The persistence of changes will be taken up later.

[13] Whenever in Group II a reproduction occurred which could not be clearly recognized by the experimenter as a rendering of one of the stimulus figures, the stimulus figures themselves were shown to the observer at the end of the experiment and he was requested to point out the figure which corresponded to the reproduction in question. In Group I this was impossible and hence among the reproductions of this group there are a few which could not be identified.

appeared to be of so many kinds and of such diversity that any attempt at classification seemed almost hopeless. No two reproductions were quite alike, and at first the most impressive fact about them was this uniqueness of each reproduction. Even with the comparatively simple stimulus figures used, it is evident that every reproduction is an individual phenomenon determined by very complex conditions which are never twice the same. One has only to examine a large number of reproductions of the same form by various Os to realize how numerous and complicated the determinants of perception and reproduction must be.

Nevertheless, after the changes had been studied for some time and after they had been compared with the reports of the observers, certain broad lines of classification emerged. Even after watching the reproductions of only a few observers, it became evident that resemblances to familiar objects which the observers saw in the figures were influencing the reproductions. A reproduction would be made with some unusual change, and in reporting on the reproduction the observer would mention casually (of his own accord or on questioning) that the figure looked like a particular object, *e.g.* a maid's apron, a fish's tail or a geological formation. It would at once become clear that the change had been of such a nature that the reproduction conformed more closely to the object than did the original. On the other hand, it frequently happened that the observer analyzed the figure verbally in such terms as 'triangle with square on top' or 'base with top part slanting.' The reproduction which followed was altered in the direction of the verbal memory. Still another kind of change could very often be distinguished in which one figure had plainly modified the reproduction of another. The observer, let us say, had drawn one form and this apparently reminded him of another which he also proceeded to reproduce. This latter form showed a change in the sense of having taken on some of the characteristics of the first form. On being questioned, the observer would state that he had remembered the latter form as *similar* to the first. This kind of change may be said to be comparable to the first kind mentioned,

except that in this case one of the stimulus figures takes the place of the familiar object. Furthermore, a certain class of changes peculiar to the 'broken' figures—those having gaps in the contour—could be distinguished. As a general rule, the gaps were reproduced smaller in the reproductions or were entirely closed up; but now and then one occurred in which the essential form of the stimulus figure had entirely disappeared. The gaps had widened and the figure had, as it were, fallen apart. It was no longer a shape, but instead two or more scattered parts of the original. Finally, a class of changes peculiar to the 'curved' figures could be made out. Occasionally one of these stimulus figures was reproduced partially or wholly in terms of straight lines. The opposite phenomenon, that of reproducing part of a straight figure as curved, never occurred. This type of change did not occur, however, with sufficient frequency in the reproductions of Groups I and II definitely to establish its validity. A separate group of experiments, to be described later, demonstrated its right to a distinct classification.

The names given to these classes of change were, in the order in which they have been described, Object Assimilation, Verbal Analysis, Figure Assimilation, Completion or Disintegration and Rectilinearity. These words do not by any means denote hard and fast categories. The classes of change are not mutually exclusive. Very frequently a reproduction shows two or more kinds of change. Object Assimilation and Completion are very often found in the same reproduction. Verbal Analysis and Disintegration are likewise often found together. With the exception of Completion and Disintegration, which are logically opposed, any kind of change may enter into combination with any other to determine a reproduction and examples may be found of all these combinations. Object Assimilation, Verbal Analysis, Figure Assimilation, Completion and Disintegration, and Rectilinearity, then, are merely descriptive names which are used to denote a few general influences among the numerous and complicated factors which determine perception and reproduction.

In order to determine the frequency with which these

kinds of change occurred, a study was made of the reproductions of Group II. Rectilinearity was not included in this study since, as was mentioned, a later group of experiments was devoted to it. The 20 observers of Group II had made a total of 689 reproductions out of a possible 1,120 figures exposed. 294 of these reproductions (43 per cent) clearly showed changes which could be classified under the five kinds (omitting Rectilinearity) described above. The results are shown in Table I.

TABLE I

CHANGES OBSERVED IN GROUP II

Obs.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Totals
Object Assim...	8	1	3		8	2	2	3	12		2	2	9	7	6	6	12	1	7	4	95
Verbal Analysis...		2		1			1	1		4		1	1		2		1		1	2	17
Figure Assim...	5	5	6	2	7	2	5	7	6	7	2	2	10	6	3	9	11	2	6	5	108
Completion....	2		3		1	2			10	10	6	4	7	1						2	48
Disintegration....	2	2	1	4	1	1	6	2				1			1	4				1	26
Total changes	17	10	13	7	17	7	14	13	28	21	10	10	27	14	12	19	24	3	14	14	294
No. of reproductions....	47	33	37	21	36	24	35	29	49	29	42	22	37	44	35	28	46	32	32	31	689

Several rules were adopted in listing the changes. In general, a change was listed only when it could be clearly recognized as falling into one of our five classes. Doubtful cases were omitted. No change was counted as Object Assimilation or Verbal Analysis unless the notes on the report of the observer explained the change. A change was placed under the head of Figure Assimilation only when either the notes or the order of reproduction explained the change, or when the change was so obviously in the direction of another figure that any other explanation was impossible. Completion was counted only when one or more gaps were wholly closed up, not when the gaps were merely drawn smaller. There was no difficulty in the case of Disintegration since, when it occurred, it was always easy to recognize.

When two or more kinds of change were exhibited by the same reproduction, only the change which appeared most

evidently to have determined the reproduction was catalogued. Therefore the table does not show the total number of times that a particular kind of change occurred in the reproductions, but only the number of time when that particular change had more effect than any other. If *all* the changes had been listed, including those cases where two or more kinds coincided in the same reproduction, the number would have been increased by at least 10 per cent.

It will be seen from Table I that Figure Assimilation is the most frequent kind of change, with 108 out of the 294 reproductions listed, or 16 per cent of the total number of reproductions made. Object Assimilation is the next most frequent, with 95 reproductions constituting 14 per cent of the total. Completion and Disintegration, with 48 and 26 reproductions respectively, together make up 11 per cent of the total. The last two kinds of change, however, can occur only in the 'broken' reproductions. When this fact is taken into account, it appears that Completion or Disintegration occur in 23 per cent of the 315 reproductions in which it is possible for them to occur. Verbal Analysis concludes the list with 17 reproductions or 2 per cent of the total.

A. Object Assimilation

Precisely defined *Object Assimilation is the term used to describe the phenomenon in which the perception of the figure involves visual or verbal imagery of some familiar object or shape,*

EXPLANATION OF CHART I

(Os' designations of objects perceived)

FIG. 1. (1) Staircase; (2) ventilator (*i.e.* ventilator on deck of ship); (3) stairs; (4) steps.

FIG. 2. (1) Lampshade (also shows Completion).

FIG. 3. (1) Pyramid with top on it (could also be considered as Verbal Analysis); (2) axe; (3) anvil; (4) bell.

FIG. 4. (1) Letterbox (also shows Completion).

FIG. 5. (1) Spade handle; (2) moosehead; (3) hammer (*i.e.* head of hammer).

FIG. 7. (1) Star; (2) bird; (3) arrow; (4) arrowhead; (5) arrow.

FIG. 8. (1) Triangle with one acute angle (also shows Completion).

FIG. 9. (1) Face (*i.e.* profile of head); (2) face; (3) irregular medieval figure.

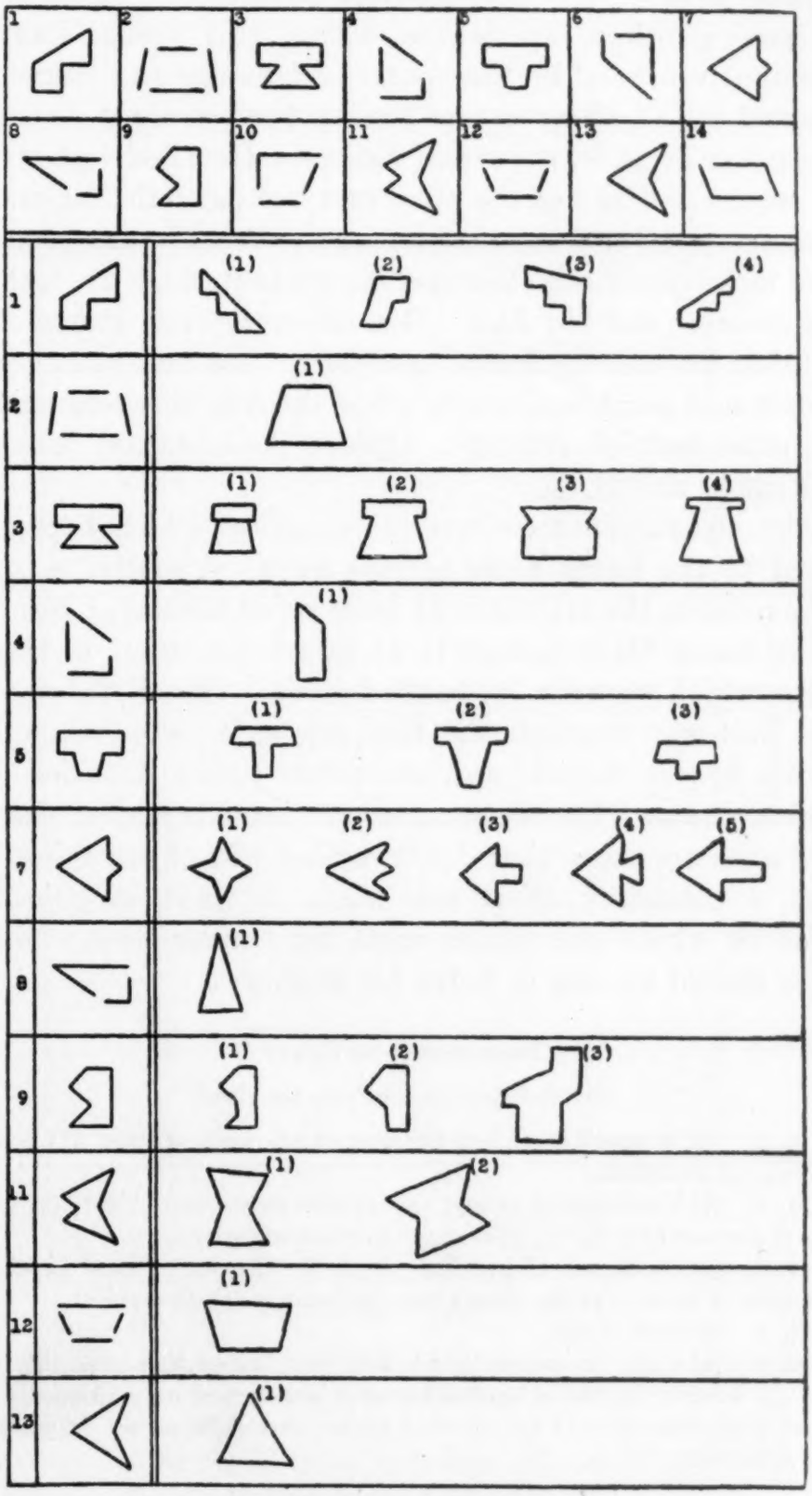
FIG. 11. (1) Hourglass; (2) tilted anvil.

FIG. 12. (1) Tub (also shows Completion).

FIG. 13. (1) Triangle.

CHART I

THE STIMULUS FIGURES OF SERIES A AND EXAMPLES OF OBJECT ASSIMILATION FROM THIS SERIES



Explanation on opposite page

and where the reproduction which follows is clearly changed so that it more nearly resembles the familiar thing than does the stimulus figure. The fact that the sight of the figure did call up, among other experiences, visual and verbal images is abundantly proved by the notes. Meanings and names were reported by all observers as having been present during the perception of at least several figures. Detailed reports were not required of any of the observers but nevertheless many of them described specific visual images, verbal images, incipient vocal movements, and less specific contents such as 'feeling of triangleness' and the like. One observer even stated definitely that he saw the forms *as objects*. He had names for all of them and perceived nearly all of them as three-dimensional and possessed of solidity. Object Assimilation was very frequent in this O.

The concomitant objects or meanings which became attached to the forms arose in two ways. Usually, according to the reports, the associations arose spontaneously; but in the case of many Os in Group II an effort was made to think of objects which were similar to the figures. Obs. F, for example, when half-way through the first exposure series, thought of 'calling figures names' and thereafter found it easier to remember them. The same observer later reported that the 'hard ones are those that don't remind you of anything.' In effect, a voluntary effort was made to think of objects by means of which the figure could be 'understood,' and the names served as cues or helps for memory.

Explanation of Chart II

(Os' designations of objects perceived)

Fig. 4. (1) Woman's torso; (2) footprint on the sands of time; (3) dumbbell; (4) violin; (5) dumbbell.

Fig. 5. (1) Two halves of an egg; (2) egg (also shows completion); (3) magnets pulling at one another; (4) egg (also shows partial completion).

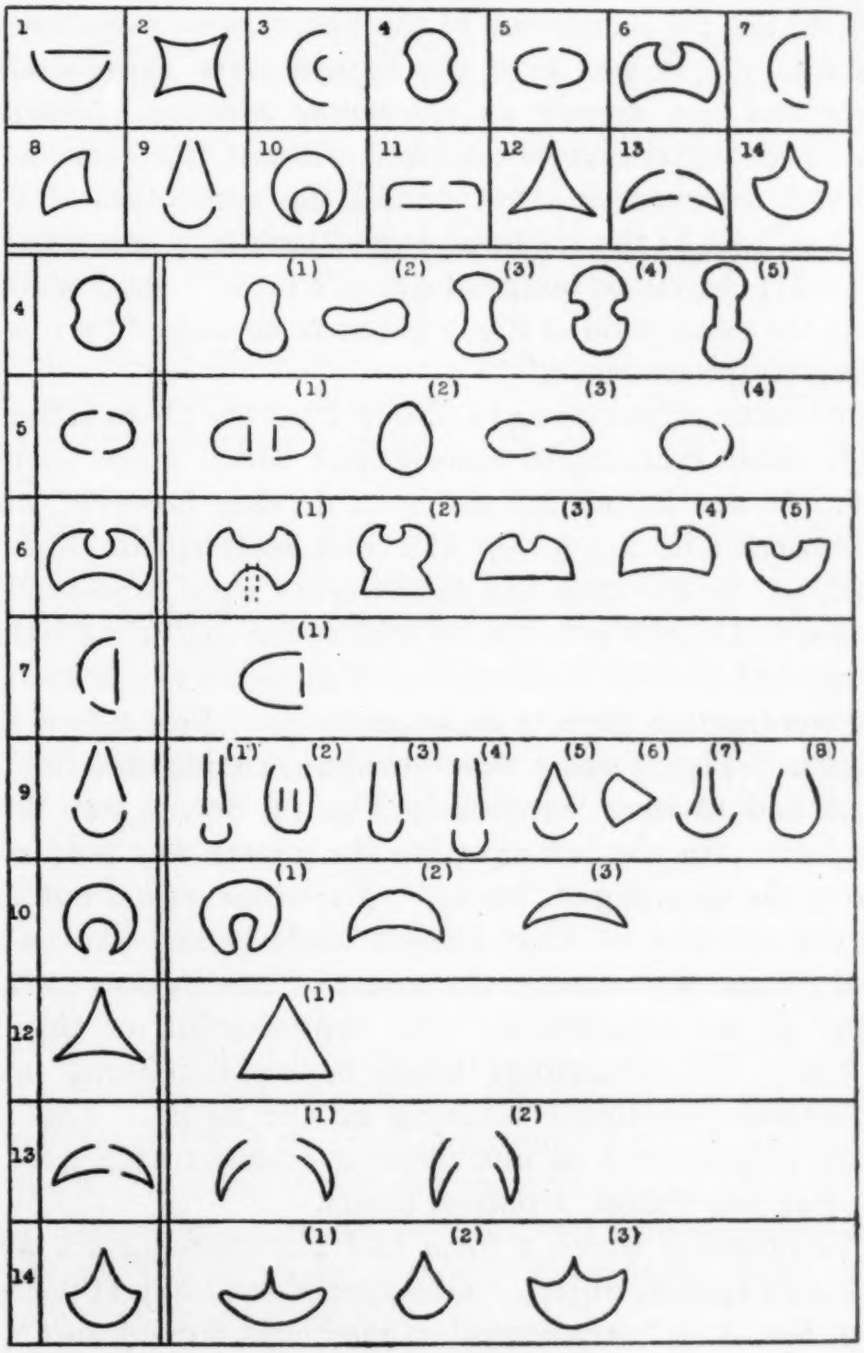
Fig. 6. (1) Battle axe (dotted lines drawn by observer to show handle); (2) maid's collar or apron; (3) Napoleon's hat; (4) helmet; (5) dress shield.

Fig. 7. (1) Half an egg.

Fig. 9. (1) Club; (2) electric light bulb (O was "not positive about the lines inside"); (3) hairpin; (4) end of baseball bat with label around it; (5) loaded doll (*i.e.* with lead in the base so as to bob up when pushed over); (6) sector; (7) pestle; (8) electric light bulb.

CHART II

THE STIMULUS FIGURES OF SERIES B AND EXAMPLES OF OBJECT ASSIMILATION FROM THIS SERIES



Explanation on opposite page

FIG. 10. (1) Blastula stage; (2) crescent; (3) moon. (It was established that the last two reproductions were not meant for Fig. 13.)

FIG. 12. (1) Triangle.

FIG. 13. (1) Horns; (2) horned toads (later called pair of horns by O).

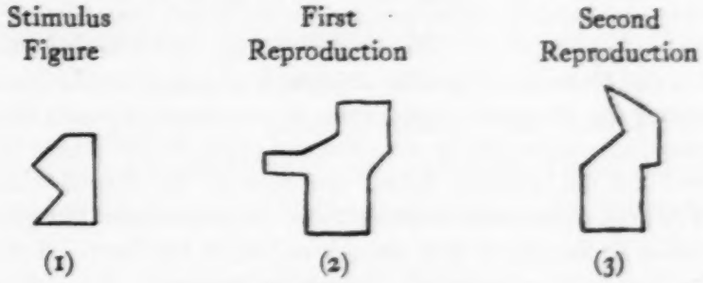
FIG. 14. (1) Meat chopper; (2) boy's top upside down; (3) basket.

The observers of Group I, on the other hand, had been instructed to try to remember the stimulus forms as strictly as possible in terms of visual images. The associations which arose during the perception of the figures were therefore quite involuntary. It was as if the figures were apprehended as *objects* and not merely as *resembling* objects. Meaningful visual and verbal images occurred without O's volition. Hu reported, for example, that during the perception of Fig. 9, Ser. A (Chart I) the stimulus form "suddenly coincided with (aroused?) the visual image of a man's face." And again that during the perception of Fig. 7 of the same series "'arrow' was explosively pronounced."

The instructions given in Group I led the Os to attempt to inhibit these meaningful associations which arose spontaneously. It was found impossible to do this, however, and all the observers in the group had well established 'object associations' by the time the experiments were concluded. In the case of Do, the attempt to inhibit the logical verbal associations which arose led to the use of nonsense words and somewhat imaginative objects as associations. Fig. 1, Ser. A was a 'goofus'; Figs. 3 and 5 were 'dishpans sitting on a fulcrum'; Figs. 2 and 12 were 'brothers'; Fig. 13, Ser. B was 'horned toads,' etc. In the last example the phrase was used merely to carry the meaning of 'horns.' The observer did not have a very definite idea of what horned toads looked like and this verbal phrase was merely the result of attempting to inhibit 'horns' as an association. (See reproduction of this O in Chart II.) In later sittings 'horns' or 'a pair of horns' became the definite verbalized meaning of the figure. The figure was never perceived as one form, a crescent with gaps, but always as two things, a pair of horns.

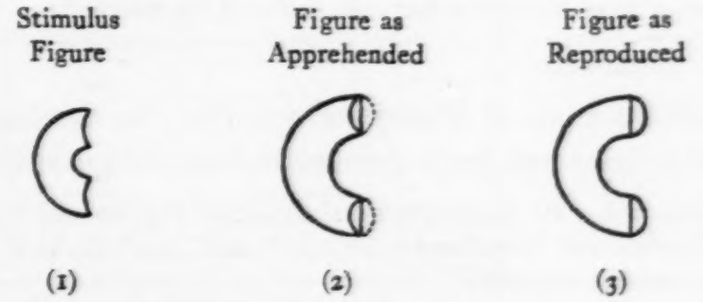
The meaning which a form had acquired did not always consist of a specific object. Observer N in Group II perceived Fig. 9, Ser. A as 'very irregular, medieval, jutting out.' His reproduction was as shown in (2). Eight months later he remembered the figure still as 'an irregular Gothic figure,' and drew (3). No specific object was here reported in imagery; but evidently the concept of 'medieval, jutting out, Gothic'

had influenced the reproductions. Certain elements of Gothic architecture, buttresses, spires, and the like may have been included in the concept together with the notion of



'irregular' and 'jutting out.' No change in the direction of a single memory image, however, which is the phenomenon usually characterizing examples of Object Assimilation, can be detected.

Another example of the way in which conceptual matter, in the absence of a definite image, may influence reproduction is found in the following drawing from a later series of experiments. The stimulus figure was apprehended as the near



side of the solid object illustrated in (2). The meaning of the figure to the observer was 'half a doughnut,' the word 'half' carrying the meaning of a half doughnut divided again into a front and a rear half. Only this general idea of a special sort of 'half' was retained in memory and when the observer came to reproduce the figure he drew the far side or 'half' of the object instead of the near side.

It may be thought that the examples which have been given in the last few paragraphs might well be classified under Verbal Analysis instead of Object Assimilation. There is some justification for such a view. The line of demarcation between the two types of change is by no means distinct and

many changes are found which could almost as easily fall into one category as the other. This difficulty will be discussed in the next section.

References to phenomena quite comparable to Object Assimilation may be found in several writers on perception. The type of change which Wulf called *normalizing*, *i.e.* a change in the direction of familiar objects, is clearly a similar phenomenon. In an investigation of the changes in orientation or position of reproduced figures, Meyer notes that errors in form frequently occurred and gives several causes for such errors.[14] It was observed that the 'memory helps,' that is to say the objects which were associated with the figures, sometimes caused errors. In these cases, the reproduction was made more similar to the object than the original figure had been. A second source of errors was the 'familiarity-tendency' (*Geläufigkeitstendenz*). An inclination was observed to reproduce the forms more similar to familiar and frequently drawn figures, such as the letter M, a triangle, etc. Both of these two causes of errors can be brought under what has here been called Object Assimilation.

Katz, who was mentioned in the introduction as having made the distinction between central and peripheral types of perception, noted that some of the reproductions made by observers of the central type were changed in the direction of familiar objects.[15]

Granit [16] published a number of reproductions made by children and showed that, although the forms used as stimuli bore little or no resemblance to objects, the reproductions nevertheless were strongly modified in the direction of similarity to animals and things which the children saw in the figures. Even the seemingly most meaningless ink blots were perceived by the children as 'pictures,' and the reproductions were representations of these pictures rather than copies of the stimuli.[17]

B. Verbal Analysis

The second kind of change which may be distinguished in the reproductions has been designated as change due to verbal

[14] P. Meyer, Ueber die Reproduktion eingeprägter Figuren und ihrer räumliche Stellung bei Kindern und Erwachsenen, *Zsch. f. Psychol.*, 1913, 64, 43 f.

[15] D. Katz, *op. cit.*, 165–168.

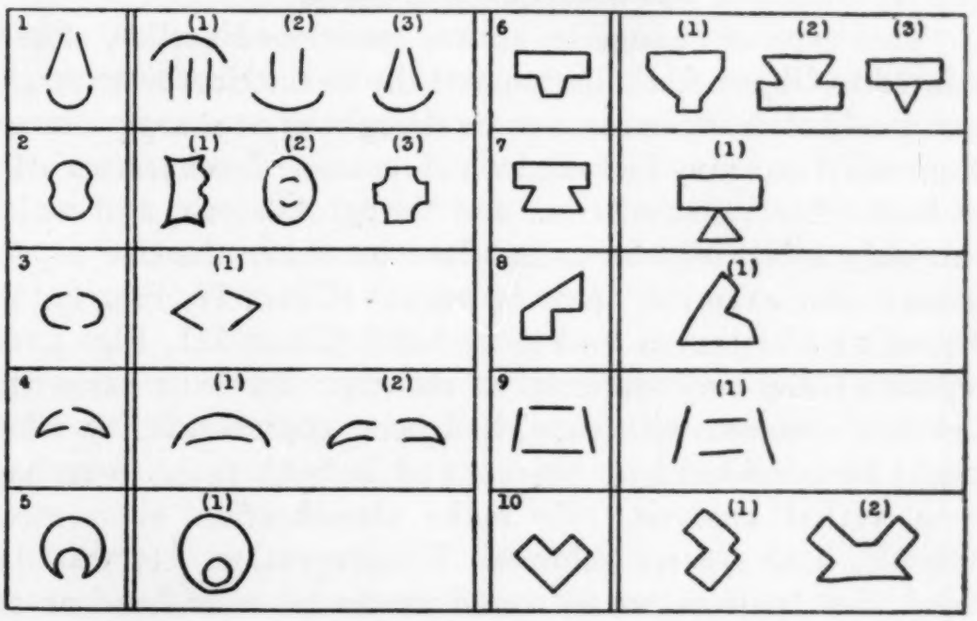
[16] A. R. Granit, A study on the perception of form, *Brit. J. Psychol.*, 1921, 12, 234 f.

[17] There is evidence that memory images undergo a change in the direction of the object. Kuhlmann (On the analysis of the memory consciousness for pictures of familiar objects, *Amer. J. Psychol.*, 1907, 18, 411) states that "the imagery tends with the lapse of time towards the imagery of the object represented by the picture, and with this change, takes on characteristics that belong to the object but which are not represented in the picture." Smith (An experimental investigation of perception, *Brit. J. Psychol.*, 1914, 6, 337 ff.) finds this same tendency in imagery for tachistoscopically exposed figures and concludes that the change towards the imagery of the object represented may, under his conditions, be immediate. Jean Philippe concludes from his study of the evolution of memory images (Sur les transformations de nos images mentales, *Rev. phil.*, 1897, 43, 486–492, and later *L'image mentale; evolution et dissolution*, 1903, 113–130.) that an image may, in the course of memory, approximate more and more to the type in which it belongs. A remembered Japanese face is reproduced more and more like the typical European face. In general, images change towards a pre-existing type, which exercises upon them a sort of attraction.

analysis. *It occurs when the stimulus form, instead of being associated with a single familiar object or shape, is analyzed verbally in any of a variety of ways and when the reproduction is so changed that it is wholly or partially a product of the verbal analysis rather than a representation of the form itself.* Some examples of this type of change are given in Chart III. The figure may be analyzed into geometrical forms in a certain relation to one another, or into several familiar objects or shapes in combination. Or the analysis may be in terms such

CHART III

EXAMPLES OF VERBAL ANALYSIS



EXPLANATION OF CHART III

(Os' designations of objects)

FIG. 1. (1) Pillars with curve (also shows Disintegration); (2) reproduction of same after second exposure; (3) megaphone in bowl.

FIG. 2. (1) Thing with two little humps; (2) reproduction of same after second exposure; (3) thing with circles taken out.

FIG. 3. (1) Two things facing one another (also Rectilinearity).

FIG. 4. (1) Half moon disconnected in two places; (2) moon broken in half (also Disintegration).

FIG. 5. (1) One circle inside another.

FIG. 6. (1) Sloped down; (2) the opposite of Fig. 7 (might also be considered Assimilation with Fig. 7); (3) point with square on top (might also be considered Object Assimilation).

FIG. 7. (1) Square on triangle (might also be considered Object Assimilation).

FIG. 8. (1) Thing with an indentation.

FIG. 9. (1) Two lines inside two others (also Disintegration).

FIG. 10. (1) Two rectangles fused; (2) two things going up and out.

as 'little humps,' 'bites taken out,' 'slanting down,' 'broken in half,' etc. An observer who has made a verbal analysis of a figure is apt to have at best only weak visual imagery accompanying it, so that whatever visual image was present at the time of perception has faded to a considerable extent by the time he comes to reproduce. What he has retained is the verbal phrase and reproduction is made in accordance with this. If the analysis was careful and the description adequately represented the figure, the reproduction was usually relatively unchanged or 'accurate.' But if, as was often the case, the analysis was hasty and superficial and was inadequate the reproduction was inadequate in the same sense.

This type of change is, as was mentioned earlier, closely related to Object Assimilation and the distinction between the two kinds of change must not be thought of as sharply drawn. Reproductions may be found which possess the characteristics of both Object Assimilation and Verbal Analysis, and which can only arbitrarily be categorized as either the one or the other. For example, 'pair of horns' (Chart II, Fig. 13, 2d reprod'n) and 'moon broken in half' (Chart III, Fig. 4, 2d reprod'n) are very difficult to classify. In both cases the figure, a crescent with gaps, had been apprehended as what might be considered an object, and in both cases there had been verbal analysis. To make classification even more difficult, both figures exhibited Disintegration. It was decided that 'pair of horns' could better be considered as an object rather than as Verbal Analysis, and that the reverse was true of 'moon broken in half.'

Despite this close relation between Object Assimilation and Verbal Analysis, however, there are two ways in which they may generally be distinguished. The first is the fact that with Object Assimilation the figure is usually apprehended as a whole, whereas with Verbal Analysis the figure is usually apprehended in parts. For example, 'triangle' (Chart II, Fig. 12, 1st reprod'n) and 'square on triangle' (Chart III, Fig. 7, 1st reprod'n) are similar, in that much the same thing has occurred in both instances. That is to say, both reproductions are quite evidently in large part deter-

mined by the verbal memory. But, in the former example, 'triangle' was apprehended as a whole, while 'square on triangle' was apprehended by parts. This distinction explains why on the one hand Object Assimilation and Completion are so often found in the same reproduction, and on the other why Verbal Analysis and Disintegration are so often found together. The second way in which the two kinds of change may be distinguished lies in the fact that the imagery occurring with Object Assimilation is predominantly visual, while that occurring with Verbal Analysis is predominantly verbal.

Characterized in these two ways, the distinction between Object Assimilation and Verbal Analysis bears some relation to Wulf's distinction between comprehensive and isolative types of perception. In the former type, it will be remembered, the figures are seen as things or as pictures of things while in the latter type the forms retain their individuality as drawings. In the first case, the apprehension is in terms of familiar, substantial objects; in the second, in terms of geometrical figures and figure-parts, such as triangles, curves, squares, slanting lines, etc. The configurations of the comprehensive type are three-dimensional and lifelike and are apprehended as a unity; those of the isolative type are two-dimensional and are analyzed into parts which may be apprehended in various ways.

Although these types of perception make a distinction between whole and part apprehension and may to this extent be compared with Object Assimilation and Verbal Analysis respectively, nevertheless the present results do not indicate either that the latter constitute types of perception or that they are as distinct and separate from one another as are Wulf's comprehensive and isolative types. Wulf seems to mean, although he nowhere states, that observers differ in possessing either one or the other type of perception. Such a conclusion could not be drawn from the present data. Object Assimilation and Verbal Analysis are regarded not as types of perception, but primarily as types of change found in the reproductions and secondarily as general influences at work in the perceptual process. Subjectively they may be con-

sidered ways of perceiving—as wholes or parts, in terms of visual or verbal imagery—but this does not make them types in Wulf's sense. Both Object Assimilation and Verbal Analysis are factors which are at work in every individual's acts of perceiving visual forms. It may be that individuals differ in the relative amounts of influence which these factors exercise in perception, but this question could not be settled by the results here obtained.

Another writer has noted changes which are directly comparable to Object Assimilation and Verbal Analysis. Kuhlmann, who studied the 'memory consciousness' and, to some extent, the reproductions of nonsense forms for a period of 90 days after presentation, finds three causes for 'errors' in the images and in the reproductions.[18] They are (1) Ambiguous Verbal Description, "The subject might, for instance, note that a form was made up of certain familiar parts, curves, straight lines, angles, etc. . . . But when he came to the recall of such a form later, he would often find that the relation of the parts had not been sufficiently observed. He would recall the names of the parts and their exact visual imagery quite readily. But he could not put these parts together so as to be recognized as correct, either from the visual imagery of the separate parts, or from the descriptive names." (2) The Influence of Associations. "The influence consisted simply in changing the form so as to resemble the associated thing more than the original form as presented did. . . . Apparently the subject forgot gradually more and more the points of difference between the associated thing and the real form, so that when in the later recalls the association was still made use of, the visual image of the associated thing took the place of the real form without any suggestion of error to the subject." (3) The Influence of Certain Standards in Forms, Positions, and Relations. Kuhlmann here includes tendencies which he finds for the forms to become symmetrical, to approach familiar geometrical figures, for lines to become parallel, etc. Clearly the first two causes of 'errors' correspond closely with change due to Verbal Analysis and with Object Assimilation respectively. Kuhlmann does not give examples of any reproductions, however, as he is primarily concerned with the introspective descriptions.

C. *Figure Assimilation*

Figure assimilation in its simplest form may be defined as the phenomenon where one of the stimulus figures is apprehended by the observer as in some respect similar to a second stimulus figure, and where the ensuing reproduction is clearly changed so as to resemble the second figure more closely than does the original. Frequently, however, the situation is more complicated. When two figures are perceived as similar, the influence of one on the reproduction of the other may be mutual. And

[18] F. Kuhlmann, On the analysis of the memory consciousness; a study in the mental imagery and memory of meaningless visual forms, *Psychol. Rev.*, 1906, 13, 335 f.

furthermore three or even more figures may be involved, each influencing the others in greater or lesser degree. There are, in fact, three grades or degrees of figure assimilation to be found in the reproductions. For the sake of simplicity, assimilation between two figures only is considered.

1. A condition where one figure was reproduced without significant change but where the other was assimilated to it, *i.e.* was changed in the direction of the first figure.

2. A condition where each figure was changed in the direction of the other, *i.e.* each took on some of the characteristics of the other.

3. A condition where only one reproduction was made, which was a combination of the two stimulus figures or of some of the characteristics of each.

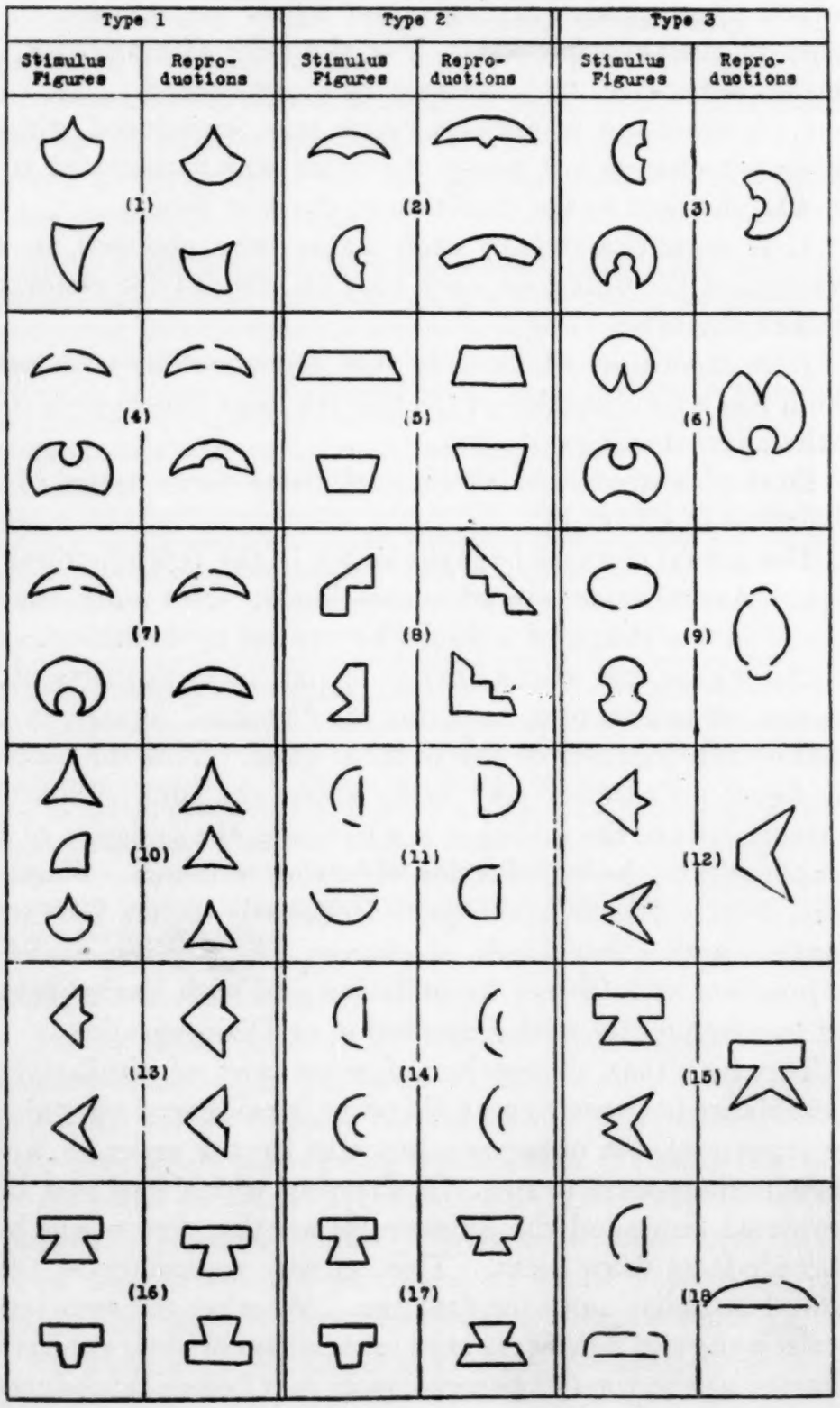
Examples are given of each of these three types of assimilation in Chart IV.

The actual changes brought about in the reproductions by Figure Assimilation are of many kinds. Not only may a change in the shape of a figure be caused by assimilation to another figure, but also a change in size, or in proportions, in position or orientation, and, for the 'broken' figures, in the number and location of the contour gaps. This influence of one figure on another may bring about the suppression of a characteristic or the addition of a new one, the omission of line components or the introduction of further elements. Furthermore, Figure Assimilation quite frequently enters into combination with other kinds of change. It is often found in conjunction with Object Assimilation and with Verbalization, and less frequently with Completion or Disintegration.

The fact that perception of some sort of similarity or resemblance between figures did occur is evidenced not only by the reports of the observers but also by the order in which reproductions were drawn. A drawing which had just been completed reminded the observer of another figure which he proceeded to draw next. This second reproduction often showed assimilation to the first one. Whether the association between the two figures, *i.e.* the recognition of their similarity, occurred at the time of perception or just before reproduction

CHART IV

EXAMPLES OF FIGURE ASSIMILATION



was made is a question which usually cannot be answered. The observers were often scarcely aware of such similarities. One figure merely made them think of another. The association had not risen to a verbal level and may have been very vague. With the observers of Group I, however, who saw the stimulus forms again and again, quite definite associations between different forms arose. The figures were remembered as falling into groups or classes, with from two to four figures in a group. Assimilation within these groups was quite common.

The perception of similarity between two or more figures by an observer was frequently complicated by the simultaneous perception of other relations between the figures than similarity. For example, in addition to perceiving a general resemblance in shape an observer would notice a particular difference between two figures, such as in Example 13, Chart IV, where one figure went 'in' and the other 'out.' The difference which was noticed between the figures was usually carried in verbal terms and changes resulted in this way which could be considered as partly due to Verbal Analysis. In Examples 16 and 17 the stimulus figures were perceived as similar except that, in a sense, one was the reverse of the other. This general idea or verbal memory of reversal conditioned the changes shown. Example 11 also shows a very similar phenomenon.

Figure Assimilation, as was stated earlier, is the most frequent kind of change to be found in the reproductions. 16 per cent of the reproductions of Group II show it clearly, or 108 out of the 689 drawings. The explanation of this fact and also of the additional fact that Figure Assimilation has not been noted in other experiments involving the reproduction of forms, except those of Meyer which will be described shortly, is undoubtedly to be found in the method used in the present experiments. Conditions were especially favorable for the influencing of one figure by another. In the first place the stimulus forms were presented in series, one immediately after another, and reproduction was required only at the conclusion of the series. The observer had to remember the

forms in a group. In the second place, all the drawings subsequent to any one exposure series were made on the same sheet of paper. The forms of a series were not only remembered together but were reproduced together. Slight associations already existing between two or more figures would be strengthened by this procedure. In her investigation of the spatial orientation of reproduced figures Meyer [19] mentions briefly that infrequently there occurred in the reproductions an associative fusion-effect (*Mischwirkung*). That is to say, the essential characteristics of two presented figures were found in one reproduction. This is clearly Figure Assimilation. The significant fact that Meyer used the same method of presentation which was adopted for these experiments, the exposure of stimuli in series, lends weight to the above conclusion that Figure Assimilation is a product of the method used.

It should be mentioned that, as a result of this method of presentation, retroactive inhibition occurred during the exposure of the series. The observers often complained that each figure as it appeared 'blotted out' the preceding figure. This inhibition was sometimes so strong that, at the end of the series when reproduction was to be made, the observer maintained that he could not remember any figures, or at best only the last of the series. Almost invariably, however, when the observer had drawn one or two figures, he suddenly remembered another and then perhaps several others until he had completed a fairly full list.[20]

D. Completion and Disintegration

The types of change which have hitherto been considered are general in the sense that they apply to all the stimulus figures alike, 'straight' or 'curved,' 'broken' or 'complete.' Completion and Disintegration, however, are specific kinds of change occurring in the broken figures only, by virtue of their essential characteristic—that of having an interrupted or broken contour. *Completion occurs when the stimulus figure*

[19] P. Meyer, *op. cit.*, 42.

[20] The average number of reproductions made after the first exposure of a series to an observer was between 7 and 8 out of a possible 14.

is apprehended as a single form, despite the gaps, and when the reproduction is drawn with a continuous contour. Disintegration occurs when, on account of the gaps, the figure is apprehended not as a single form but as two or more pieces or segments, and when the reproduction is drawn with such a widening of the gaps as to make the figure fall apart and lose its characteristics as a form. An observer whose reproduction exhibits Completion may or may not have seen the gaps in the stimulus figure. But he had apprehended the figure as essentially a single, unitary form. The gaps were not significant parts of the perception, and the figure was reproduced, accordingly, as a complete form. For example, Obs. A in Group II, upon first seeing Series A, reproduced two of the broken quadrilaterals without gaps. After the second exposure, as if having noticed the gaps for the first time, he reproduced the same two figures with gaps at all four corners. Obs. Sch in Group I, after having seen the forms repeatedly and therefore having become fully aware of the gaps, still so definitely perceived the broken figures as wholes that he adopted the habit of drawing a continuous contour and then erasing out a few gaps in appropriate locations.

Absolute Completion, as defined above, *i.e.* the closing up or disregarding of all the gaps of a figure, occurred in only about 15 per cent of the broken reproductions. But if the cases of partial completion are counted, which include both reproductions where the gaps are fewer in number and reproductions where the gaps are drawn smaller, almost all the broken reproductions except the 8 per cent exhibiting Disintegration will have been accounted for. In particular, the quadrilateral figures of Series A were consistently reproduced by all observers with smaller and sometimes with fewer gaps. Two examples of partial completion for Series B figures are given in Chart V. They are Fig. 8, 2d reprod'n and Fig. 10, 2d reprod'n.

Disintegration involves a type of apprehension wholly different from that described above. An observer whose reproduction shows this kind of change has perceived not a single form but instead a number of lines or angles which are

CHART V

EXAMPLES OF COMPLETION AND DISINTEGRATION

Stimulus Figure	Examples of Completion	Examples of Disintegration
1	(1)	(2)
2	(1)	(2) (3) (4) (5) (6)
3	(1)	(2) (3) (4) (5)
		(6) (7) (8) (9)
4	(1)	(2) (3) (4) (5)
5	(1)	(2)
6	(1)	(2) (3) (4)
7	(1)	(2) (3)
8	(1) (2)	
9	(1)	(2) (3)
10	(1) (2)	(3) (4) (5)

Explanation on opposite page

usually only vaguely related to one another in position. Obs. G, Group II, after having made two reproductions showing pronounced disintegration, stated that "there were a lot of angles [referring to the first four quadrilateral figures in Chart V]. There ought to be about four but I can only remember two." Among the reproductions of this O, who saw the broken figures as a 'lot of angles,' there were 10 instances of Disintegration. No Completion occurred.

The kind of apprehension which leads to Disintegration is closely analogous to that which occurs in Verbal Analysis. In both types the figure is perceived not as a whole or unit but in parts. As may be seen from the explanatory notes on Chart V and also from those on the broken reproductions of Chart III, Disintegration and Verbal Analysis are frequently found in the same reproduction, and it is sometimes impossible to say whether a change is one thing or the other. (For example, Chart V, Fig. 5, (2), and Chart III, Fig. 9, (1); also Chart V, Fig. 9, (3), and Chart III, Fig. 1, (1) and (2); also Chart V, Fig. 10, (4), and Chart III, Fig. 4, (2).) Conversely, Completion and Object Assimilation frequently are found to-

EXPLANATION OF CHART V

(When no notes are given on a reproduction, the drawing is either self-explanatory or O made no report.)

FIG. 1. (2) Disintegration and also simplification to triangle.

FIG. 2. (2) Two lines. (The left-hand line was especially vivid and hence correct. Also note symmetry); (4) two angles; (5) the same after second exposure. Note that right angle was correct.

FIG. 3. (2) Symmetry; (3) simplification to triangle; (4) simplification; (5) symmetry; (6), (7), (8), (9), four reproductions by Hu, Group I, of this figure after four consecutive exposures. (6) and (7) were merely perceived as angles facing one another, although in (7) the lower one was noted as a right angle. In (8) there is still assimilation to the old apprehension, although the linear relations are correct. In (9) the reproduction is nearly accurate.

FIG. 4. (4) Unconnected lines.

FIG. 5. (2) Four lines, the horizontal inside the vertical (also Verbal Analysis).

FIG. 6. (1) Completion plus Object Assimilation: parallelogram.

FIG. 7. (1) Completion plus Object Assimilation: egg.

FIG. 8. (2) Example of partial completion.

FIG. 9. (1) Completion plus Object Assimilation: electric light bulb.

FIG. 10. (2) Example of partial completion; (3) two points (also Verbal Analysis); (4) two things pulled down at each end (also Verbal Analysis); (5) observer merely perceived two things facing one another and remembered that they were curved.

gether in a reproduction of one of the broken forms. The perception occurring with these two kinds of change is typically of a single thing. The distinction therefore between whole and part apprehension which was made with regard to Object Assimilation and Verbal Analysis is here further corroborated.

In connection with the reproductions given in Chart V, two particular factors should be noted which are effective in determining the nature of the reproductions. First, when Disintegration occurs and a figure is reproduced merely as a group of lines or angles, there is a tendency to draw the lines or the angles in such a way that they are symmetrically related as to position. The form which holds the lines in place having disappeared, the next best determiner of position is symmetry. This factor of symmetry in determining the reproductions of figures has been noted in several experimental studies.[21] Secondly, in several of the reproductions of the first four quadrilateral figures given in Chart V, it may be seen that the grouping of lines and angles has taken the general form of a triangle. This phenomenon has been indicated in the explanation of the chart as 'simplification.' There is apparently a tendency towards a three-sided arrangement in reproduction when the original four-sided form is not perceived as such.[22]

E. Rectilinearity

Just as the types of change last discussed depend upon the use of broken and complete figures as stimuli, so the kind of change now to be considered arises in connection with the

[21] See P. Meyer, *op. cit.*, 42; A. R. Granit, *op. cit.*, 237–240; L. Hempstead, *op. cit.*, 188; and F. Kuhlmann, On the analysis of the memory consciousness; a study in the mental imagery and memory of meaningless visual forms, *Psychol. Rev.*, 1906, 13, 336.

[22] With regard to Completion, a few investigators have referred to a tendency to fill in or complete figures when reproduced. Hempstead, *op. cit.*, 187, finds a disposition towards "the formation of a continuous from a discontinuous figure." Meyer, *op. cit.*, 42, notes as one of the types of errors found in the reproductions the completion of a figure, and gives as an example a case where an acute angle had been reproduced as a triangle. F. Meakin (Mutual inhibition of memory images, *Psychol. Monog.*, 1903, 4, 263) finds that the visual memory image of a broken form has a strong tendency to be completed when the broken form was presented side by side with the completed form. No mention of anything similar to Disintegration has been found in the literature.

straight and curved figures. It had been observed in some of the reproductions of Series B, the curved figures, that occasionally part or all of the drawing would be made in terms of straight lines. The opposite phenomenon, that of reproducing part of a straight figure as curved, never occurred. These facts seemed to indicate that when an observer is not clear as to the nature of one or more component lines of a form, he is more apt to reproduce them straight than curved.

To test this hypothesis and also to find out whether or not there was any significant difference between straight and curved figures in perception and memory, a new group of experiments was undertaken (Group III). Two new series of forms were made up, 25 of which were composed of straight lines and the other 25 of which were composed entirely of arcs of circles. In the attempt to make the two series comparable, the figures of the two series were constructed as far as possible so that they were of the same order of complexity or 'difficulty.' The 25 straight figures had an average of 4.6 sides. The 25 curved figures (counting a 'side' an arc of 180° or less) had an average of 4.3 sides. On this basis of comparison, the straight figures were slightly more complex than the curved figures.

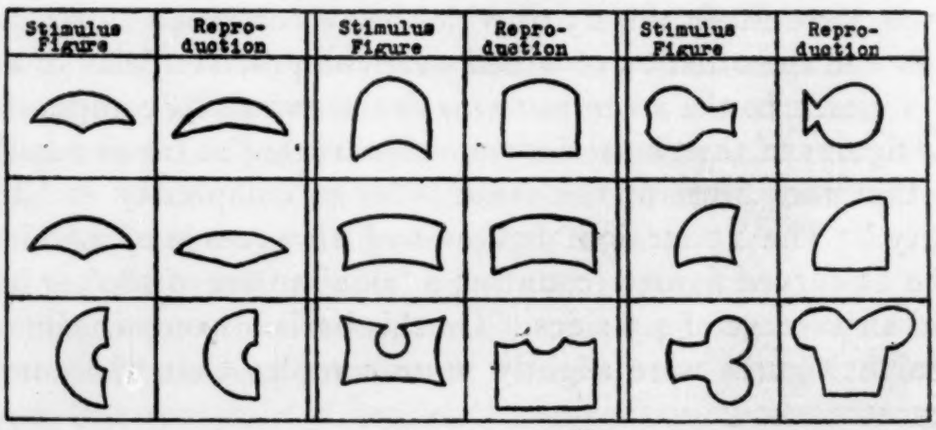
The stimulus figures were drawn on the faces of blank playing cards and were exposed by placing one card after another on a table in front of the observer, each card covering the one just presented. One card was exposed every two seconds, the time being regulated by following the rhythm of a half-second pendulum which was allowed to beat throughout the experiment. The cards were shuffled anew for each new O, so that in contrast to the experiments of Groups I and II, the order of presentation did not have any influence in the reproductions taken as a whole. 15 observers were used. With five of these the 25 curved figures were exposed and reproduced, then the 25 straight figures. The order of exposure was reversed for alternate subjects. With another five Os, all 50 figures were presented in one series, the figures being arranged in chance order. With the remaining five Os, ten figures were presented at a time, each ten consisting of five

straight and five curved figures. Reproductions were made after each group of ten figures.

For each of the three methods of presentation more straight figures were remembered than curved, even though, as was mentioned, the straight figures were slightly more complex than the curved. Out of 277 reproductions, 149 were straight and 128 curved, an advantage of 17 per cent for the former. More important than this, however, was the fact that approximately 20 per cent of the curved reproductions exhibited

CHART VI

EXAMPLES OF RECTILINEARITY



rectilinearity, *i.e.* had straight line components instead of curved. Less than 3 per cent of the straight reproductions had curved lines, and these instances occurred in the last two methods where straight and curved figures were presented together. That is to say, the chances being equal, more curved parts of figures were reproduced straight, than straight parts curved.

In order to find out whether this fact might be due to the effect of Figure Assimilation between straight and curved figures, the former tending to assimilate the latter more than the reverse, the 25 curved figures alone were presented to five new Os. It was found that curved parts were still reproduced straight. About one-fifth of the reproductions showed this type of change. There seems to exist, therefore, a genuine change in the direction of the rectilinear. The change is independent of the presence of straight-line figures among the stimuli, and is apparently due to a factor in the perception

of curved figures. Chart VI contains a few examples of these changes from curved lines in the stimulus figures to straight lines in the reproductions.

The results of Wulf and those of the present experiment

A. Sharpening, Levelling and Structurally Conditioned Change. It will be remembered that Wulf classified the changes exhibited by his reproductions in two ways. Primarily, all changes fell either into the category of sharpening or into that of levelling. Secondarily, the changes were caused either by normalizing, emphasizing or the characteristics of the 'structure' itself.

With regard to the first classification, sharpening and levelling were defined respectively as the exaggerating and eliminating of a characteristic of the stimulus figure. It is difficult to see how the introduction of these two categories contributes any positive information as regards the perception and reproduction of forms. The classification is strictly logical and the 'characteristic' which is intensified or diminished depends entirely on the point of view of the experimenter. The observer might have perceived a very different characteristic from that which the experimenter saw, and hence what was sharpening for one might be levelling for the other. For example, suppose that two parts of a figure not quite equal in size are reproduced equal or more nearly equal than they had been. If 'unequal size' be considered the 'characteristic' of the figure, then the change described is levelling. But if 'nearly equal size' be considered the 'characteristic,' then the change is sharpening.

An examination of the forms which Wulf used as stimuli explains why the changes could so easily be divided into two opposite categories. Either by design, or by chance, most of the stimulus figures were of such a nature that they could vary only in two directions. The commonest type of figure used was one in which there was two elements, one element differing somewhat from the other, such as two triangles of different shape having a common base; two connected forms of the

same shape but having a different size, etc. If the two elements in the figure were equalized, this constituted levelling or the suppressing of a characteristic. If the two elements were further differentiated, this constituted sharpening or the exaggerating of a characteristic.

The stimuli used in the present investigation, in contrast to those described above, were single forms and furthermore they were uniformly contour forms. With such as these, there was a wide possibility for variation, or, in other words, changes could take place in a variety of directions. No evidence for two opposite types of change was found. In brief, then, sharpening and levelling are in the first place distinguishable only in a logical sense, and in the second place are due to the peculiar nature of the figures used.

With regard to the secondary classification of Wulf's reproductions, a fairly close counterpart for normalizing can be found in Object Assimilation. As for emphasizing, or the exaggerating of some characteristic of a form owing to particular attention to that characteristic during perception, the change is quite intelligible in the light of the examples which Wulf gives. Most of these examples could be regarded as coming under Verbal Analysis. It is when we come to consider the structurally conditioned change that difficulties arise. Wulf states that the change in a reproduction is here due to the nature of the form (*Struktur*) itself. He is evidently not speaking of the physical form but of the phenomenal, or perhaps the conceptual form.[23] This perceived configuration is regarded as having inherent tendencies to change in a certain direction. The examples which are given of this type of change consist of four reproductions which became wholly or to a greater degree symmetrical, one reproduction in which the angles of a zigzag line became more acute, and one reproduction in which a flat curve connected to a straight line was drawn with a sharper curvature because it had a greater 'weight' than the straight line. In one of the

[23] Just what a conceptual form would be like is difficult to state. Rignano mentions Locke's difficulty in trying to form a concept of triangle and criticizes the configurationists on this score. E. Rignano, The psychological theory of form, *Psychol. Rev.*, 1928, 35, 128–133.

four reproductions which became symmetrical, there had been a 'normalizing apprehension' which would ordinarily have caused a change in the opposite direction had it not been for the stronger influence of the structurally conditioned change. In another, there had been an 'emphasizing apprehension' which likewise would have been expected to cause a change opposite to that of the structurally conditioned change. Apparently, then, this type of change is *independent of the way in which the figure is perceived.*

Precisely how this change comes about is not clear. Wulf states, it is true, that *all* the changes, whether they be sharpening or levelling, are to be explained by the fundamental laws of the *Gestalt.* The most general of these laws is the Law of Pregnancy, which is to the effect that every configuration tends to become as 'good' as possible.[24] One is led to infer that the structurally conditioned change, then, is due entirely to this tendency towards a specific, lucid, complete or 'good' *Gestalt.* The configurationist's *form* is apparently something which, in its own right and independent of the experience of the observer, possesses the capacity to change. A configuration is dynamic, and is governed by the laws of its own structure.

The issue is this: Is the change in a reproduction of a perceived form caused by the influence of past perceptions on the perception and memory of that form, or is the change caused by the nature of the form itself? No attempt is made in the present study to settle this issue. There will have to be experimental evidence on the question of whether or not there are forms which, when perceived, always and invariably tend to change in a certain respect, without reference to the way in which the forms were apprehended, the associations which accrued, etc. No evidence for the existence of such forms was found in the present results. The types of change here observed may all be explained, it is believed, by the supposition that the experience of the individual has brought into existence certain habitual modes of perception, and that these perceptual habits, rather than the laws of configurations, condition the changes observed.

B. Persistence of Changes. Wulf particularly emphasizes

[24] Wulf, *op. cit.*, 370–373.

two facts in connection with his reproductions, at different times, of the same figure. (As has been stated, his observers first reproduced the stimulus figure 30 seconds after exposure, then after one day, after one week, and sometimes after two or more weeks.) First, a change took the direction either of sharpening or of levelling from the beginning, and this direction was maintained in the later reproductions. The direction of change was reversed in the case of only three series of reproductions. Secondly, a change once started in a certain direction was *continuous* in that direction; in other words, there was consistent progress in the sense of greater sharpening or levelling with each succeeding reproduction.

The interpretation of these two facts, of the unidirectional character of the change and of the continual increase in the amount of change, as evidence for a dynamic *Gestalt* which merely follows the laws of its own nature, is not borne out by the present experiments. It was found that changes did persist, in the sense that a figure which had been apprehended in a certain way and was changed accordingly was remembered in the same way and reproduced with the same change in later reproductions. But the change was never independent of the way the figure had been apprehended. Observer Br in Group I at first perceived Fig. 9, Chart I as similar to Fig. 1, Chart I. His reproductions of Fig. 9 during the first three sittings exhibited pronounced assimilation to Fig. 1. Then for two experimental sittings he either did not notice the figure or forgot it, for no reproductions were made. At the sixth sitting he started reproducing Fig. 9 again with an entirely different sort of change. There was no assimilation whatever to Fig. 1. He stated that it seemed to be an entirely new figure which he had never noticed before.

The dependence of the reproduction on the manner in which the figure was perceived, as illustrated by the fact just mentioned that the same figure apprehended at different times in different ways will lead to widely different reproductions, is not original with this investigation. Wulf emphasizes the importance of the *Auffassung* throughout his paper, and he states in his summary that the direction of change depends

upon this original way in which the figure is apprehended, a particular type of apprehension leading to a particular type of change. With this aspect of Wulf's study the present investigation is in full accord. It is only when he considers the structurally conditioned change and the implications of unidirectional and progressive change during memory that an apparent contradiction arises.

With regard to the progressive nature of Wulf's changes, it was found that for two of the present kinds of change, Object Assimilation and Completion, there was some tendency for the change to become greater, the longer the figure was in memory. A figure which had been apprehended as similar to an object often, but not invariably, was reproduced more and more like the object as time went on. A form grasped as 'electric light bulb' and reproduced with some assimilation to the object was reproduced 6 months later as completely similar to the object, even to the adding of lines inside the figure to represent filaments. Another form apprehended as 'footprint' and slightly changed in that direction, was reproduced 6 months later with the precise shape of a footprint. As for Completion, nearly all the reproductions of broken figures after 6 months showed full attainment of this kind of change, and those remaining showed considerable progress towards it. The interpretation of these facts, however, is not the interpretation which Wulf gives. It seems more plausible to believe that progressive change is due not to the dynamic nature of the configuration but to an *increasing degree of assimilation.*

C. Assimilative Perception. Wulf, it is true, admits[25] that a possible explanation for normalizing could be found in Wundt's doctrine of *assimilative perception.* There are evidently factors within the observer which contribute towards determining the perception, in addition to the influence of the stimulus figure itself. It is supposed that these factors are nothing but memories of earlier perceptions. Such memories are aroused by association and *fuse* with the image aroused by the stimulus figure into a single perceptual image. If, then,

[25] Wulf, *op. cit.*, 367.

after an interval a reproduction of the figure is required, the assimilation becomes quite evident since the older traces, which fade more slowly than new ones, are present to the exclusion of the new ones.

Wulf, however, rejects this explanation and proposes one more in keeping with the *Gestalt* hypothesis. When a figure is apprehended as similar to a familiar object, it does not mean that an earlier perception or an average of many earlier perceptions is re-aroused. What happens is that the organism, in its response to the stimulus figure, makes use of certain familiar methods (*Verfahrungsweisen*) and configurations (*Strukturen*).[26] These configurations have already become stable. A change in the direction of one of these familiar configurations is due to the fact that it controls all of the perceptual data and, being stable, it asserts itself (*sich durchsetzt*) more and more as time goes on.

It does not appear that there is a very radical difference between the two explanations. The notion of an old memory image fusing with a new perception, and the notion of an old configuration asserting itself over a new configuration differ essentially only in the terms used. If an explanation must be advanced for the facts which have been observed, the present trend of psychology would indicate that it can best be put in functional terms. It has been noted that forms change towards objects, towards the verbal descriptions made of the forms, and towards other forms perceived contiguously in time. The first two phenomena might be explained by the hypothesis that new perceptual activity in an observer takes place in terms of old perceptual habits. The third phenomenon would be due to the fact that one train of perceptual activity is modified by another if they overlap in time and if they have any elements or processes in common. 'Assimilation' in perception would then be caused not by a fusion of images, nor yet by the influence of one configuration on another, but by the turning of a new perceptual process into earlier channels of perceptual activity.

[26] Wulf, *op. cit.*, 373.

Summary

1. A reproduction of a visually perceived form is frequently changed in the direction of a familiar object if the object has previously been associated with the figure in consciousness.

2. A change in a reproduction is often conditioned by cues from a verbal analysis which was made of the form during perception.

3. A reproduction of one figure is frequently changed in the direction of another figure if the two figures have been previously associated in consciousness.

4. Gaps or breaks in the contour of a figure are either partially or wholly closed up in the reproduction, or else the figure 'falls apart' into separate units.

5. Curved lines are much more apt to be reproduced as straight lines than the reverse.

6. The changes observed in these experiments have not been interpreted as evidence for a single law determining the changes of configurations, but rather as evidence for the existence of perceptual habits which have arisen in the individual during experience. In general, the nature of a change found in the reproduction depends upon the manner in which the figure was apprehended.

(Manuscript received July 17, 1928)

PROTRACTED PASSIVE OSCILLATION AND INTERMITTENT ROTATION OF THE BODY; VARIABILITY IN PERCEPTION AND REACTION

BY ROLAND C. TRAVIS[1]

When a subject is passively oscillated in simple harmonic motion and at certain velocities and accelerations, either in rotary or rectilinear directions, the direction of the motion may be perceived even though the eyes are covered and auditory cues masked. Pathological and physiological experimentation with human subjects as well as with animals has shown that the labyrinthine receptors function in the perception of, and reflex adjustment to, rotary and rectilinear changes in the velocity of the head. The perception of motion, however, cannot be clearly localized as to its sensory origin in the same way that light and sound are localized. Sometimes the consciousness of passive motion seems to result from certain reflex adjustments of the organism to labyrinthine excitation, while with certain experimental controls the conscious cues to motion can be definitely localized in the head.

In a previous investigation (1, 2) of the sensori-motor consequences of passive rotary and rectilinear oscillation of the body, vision and kinaesthesis were found to play predominant rôles in the perception of the direction of bodily motion when cues from these senses were available. When the body was free to move kinaesthesis was at least ten times more effective than vestibular stimulation in the perception of passive *rectilinear* oscillation. Visual cues showed a still higher order of effectiveness. The relative rôles of the auditory, organic and cutaneous receptors were not considered in that investigation; but precautions were taken to eliminate or mask any cues that might come from these organs.

That investigation was planned to determine the relationship between the adequacy of voluntary compensatory response and the amplitude and frequency of oscillation, rather than the effects of prolonged stimulation. It was found that the adequacy of response to vestibular stimulation decreased with a decrease of either frequency or amplitude of oscillation. The relation between the average acceleration and correct

[1] National Research Fellow in Psychology. The writer wishes to express his gratitude to Professor Raymond Dodge for his invaluable criticisms and suggestions, and to the Institute of Psychology, Yale University, for the facilities and cordial hospitality which made this research possible.

response irrespective of frequency was approximately rectilinear from far below the 50 per cent threshold to values at which 90–100 per cent of the responses were correct. Some data were also obtained as to the facilitating and inhibiting effects that other receptors produce on labyrinthine excitation in subliminal, liminal and supraliminal oscillation and intermittent rotation of the body.

The present report is primarily concerned with the variability in perception of, and response to, successive stimuli in protracted passive oscillation and intermittent rotation of the body in rectilinear as well as rotary directions. The experimental data were obtained in most part while the previous experiments (1,2,3) were in progress. The experimental methods and techniques were described in detail (in 2 and 3). Only the main features need be repeated here.

Experiment I

Protracted passive rotary oscillation with the subject at the axis of rotation

A typical record of manual compensation to oscillation, 2 degrees in 4 seconds, with the subject's head supported by rests at the axis of rotation, the eyes covered, and auditory cues masked is shown in Fig. 1, *A*. The smooth curves are records of the movements of the platform, the irregular curves are records of the compensatory manual response. Time is recorded in seconds.

During this series of 80 successive half-oscillations, only part of which is shown in Fig. 1, *A*, the compensation record indicates a marked fluctuation in the perception of movement and consequent response varying from positive, through zero, to negative reactions. The compensation curves which are smaller in amplitude than those of the platform indicate partial compensations or positive reactions. Those which have a greater amplitude than that of the platform curves indicate negative reactions. Those which have an amplitude equal to that of the platform curves indicate zero compensation or no reactions. Two degrees in 4 seconds is slightly above the 50 per cent threshold of Subj. RD.

The various kinds of response seem to occur in volleys or waves, giving a rhythmical appearance to the record as a whole. This more or less rhythmical fluctuation of the ob-

jective record, which corresponds roughly to the introspective report, is indicative of variations in the excitability or irritability of the neuro-vestibular system in response to repeated

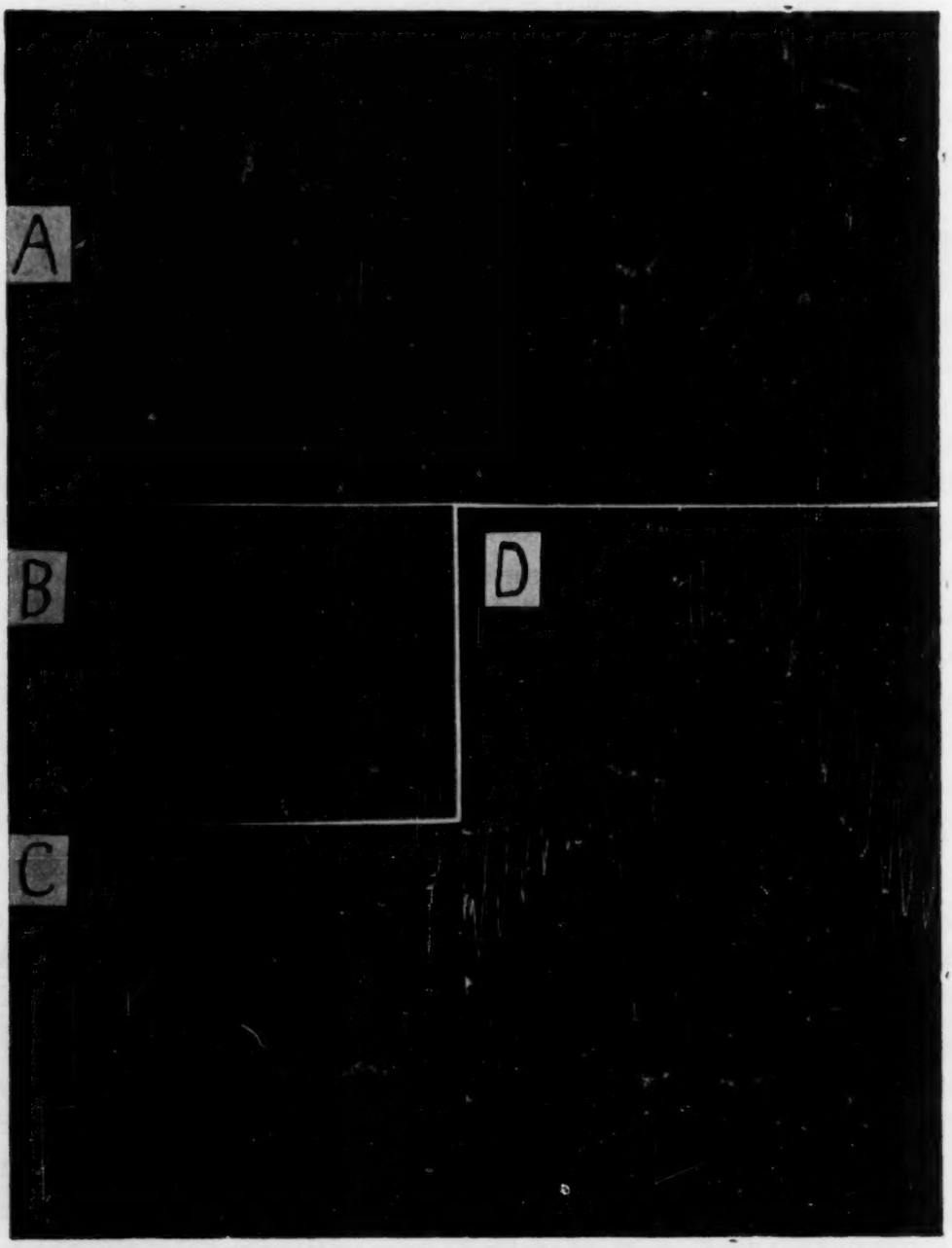


FIG. 1. Records of the movements of the platform and manual compensation for rotary oscillation with the subject at the axis. *A* represents manual compensation to oscillation, 2 deg in 4 sec (Subj. RD), only 35 of the 80 oscillations are shown. *B* represents manual compensation to hallucinatory movement during the period when the platform remained physically fixed. *C* represents manual compensation to 1 deg in 4 sec superimposed on longer waves unlike the objective rhythm (Subj. RD). *D* is the same as *C* except oscillation, 2 deg in 4 sec (Subj. RCT).

stimulation. Such lowering and heightening of irritability as is experimentally demonstrated here is of fundamental importance in interpreting thresholds, the negative and positive responses to frequently recurring stimuli of constant intensity in protracted oscillation, as well as refractoriness of response. The concept of threshold or limen as applied to voluntary response to vestibular stimulation has been considered at length in the previous monograph. It did not satisfactorily fit those data except as a convenient central measure. Curves of relationship and distributions of percentages of positive, zero and negative reactions gave a more adequate picture of response phenomena.

There is a regular increase in the number of negative responses as the average acceleration of oscillation is reduced to or below the 50 per cent threshold. In connection with other studies (4, 5) of the effects of faint stimuli, it suggests some normal variation in the mode of response of a neural system with changes in intensity of stimulation. The occurrence of more negative reactions than positive in response to long-continued stimulation at intensities otherwise liminal or slightly supraliminal is presumably due to some variation in the irritability of the system as a consequence of previous faint stimulation.

Reproductions of reaction curves of partial true compensation superimposed on longer waves unlike the objective rhythm are shown in Fig. 1, *C* and *D*, which represent compensation of Subj. RD to 1 deg in 4 sec, and of RCT to 2 deg in 4 sec. The main characteristic of these large waves, introspectively as well as objectively, is that the clockwise movements seem, for a while, to be longer and more intense than the counter-clockwise, then the counter-clockwise seem to be longer and more intense than the clockwise movements. In some instances there was total imperceptibility of the clockwise movements for several seconds, and *vice versa*, depending somewhat on the amplitude and frequency of oscillation. This rhythmical variation in the irritability of the neuro-vestibular system to passive clockwise and counter-clockwise movements cannot be wholly attributed to peripheral excita-

tion, because of the fact that a similar phenomenon is manifest during the non-stimulated period when the platform remains physically fixed and the subject responds to hallucinations of motion in definite directions. A reproduction of such a record is shown in Fig. 1, *B*. The phenomenon cannot be attributed to respiration because of the relatively long waves. In the light of these records and previous data (2) on hallucinatory motion during the still-periods the hypothesis that central factors of various possible origins facilitate or inhibit the perception of passive oscillation seems reasonable.

A further interpretation of the alternate increase and decrease in clearness of the clockwise and counter-clockwise movements may be given in the light of Maxwell's work (6) on the dynamics of the semicircular canals in dogfish. Maxwell found that the stimulus for the crista of the right horizontal canal is rotation to the right, and the stimulus for the left is rotation to the left. It is possible that rivalry between the right and left neuro-vestibular systems may operate in the case of man. But the interpretation of the function of the human labyrinth in terms of animal experimentation is probably dangerous even though theoretically suggestive. A point against attributing the phenomenon to rivalry is that in rectilinear oscillation a similar variation in clearness is manifest in the backward and forward movements. Here the canals both move in the same direction, and, since there is no angular change, rivalry between the right and left canal systems could not have occurred. Further knowledge of the anatomy and physiology of the receptor or receptors for rectilinear oscillation is necessary before the probability of rivalry between the two labyrinths can be adequately estimated.

In view of the fact that only certain frequencies of oscillation cause alternation in the direction of apparent motion, it is reasonable to suppose that the movements which are more adequately perceived fall in a period of increased excitability of the vestibular system, while the movements which are vaguely perceived or unperceived fall in a period of relative refractoriness of the system. This hypothesis has still other

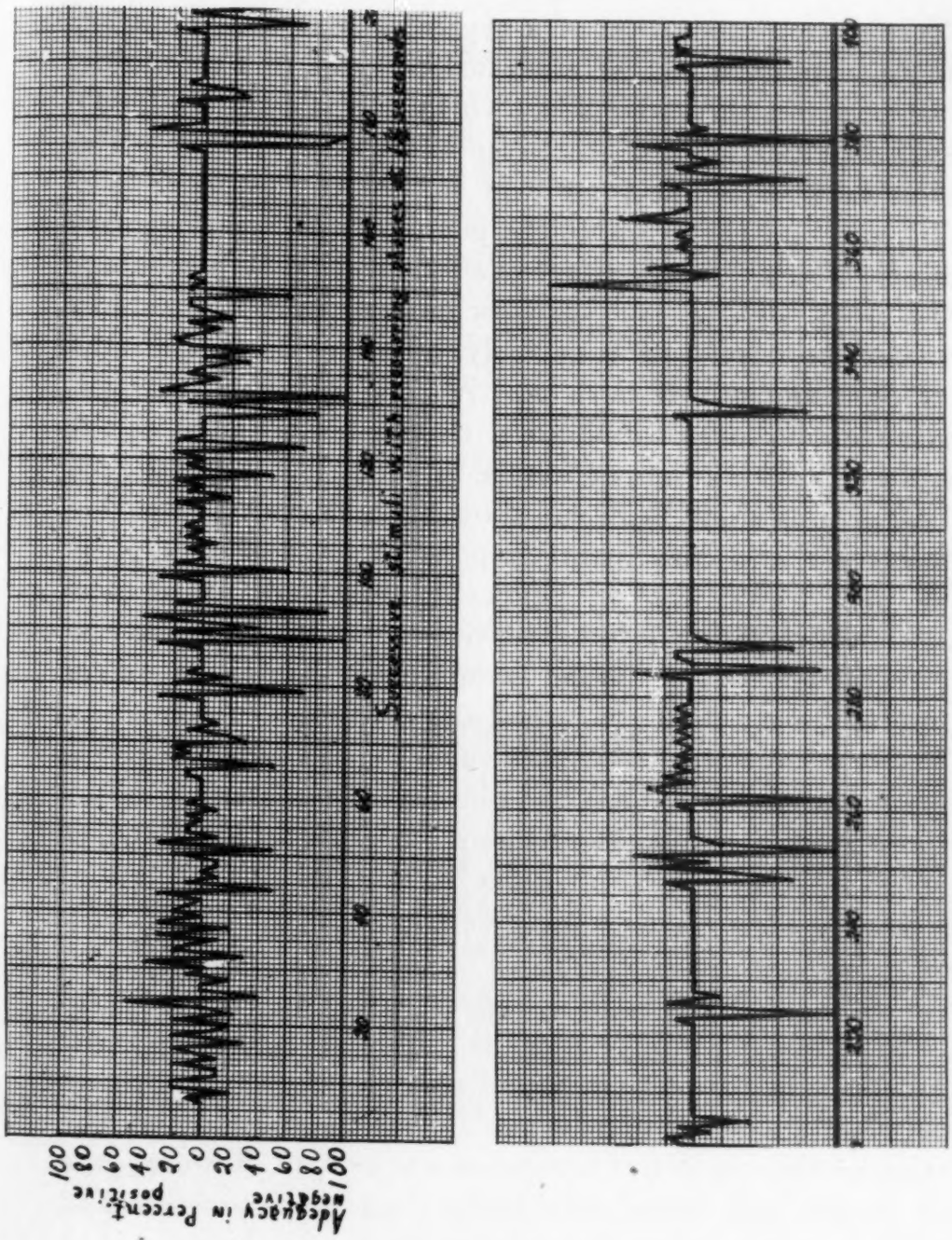

Inaccuracy in Percent
negative positive
100 80 60 40 20 0 20 40 60 80 100
Successive 3 sec periods of rotary oscillation
30 60 90 120 150 180 210 240 270 300 330 360

FIG. 2. Subj. RD. Variation in percentage of positive and negative compensation to successive oscillations of 0.5 deg in 3 sec for rotary oscillation with the subject at the axis. Twenty-five per cent of the responses were correct.

facts in its favor, since relative refractoriness of the vestibular system to frequent intermittent rotary movements in the same direction has been demonstrated (3).

Graphic representation of a typical protracted voluntary response to passive rotary oscillation, 0.5 deg in 3 sec, below the 50 per cent threshold is shown in Fig. 2, for Subj. RD. Twenty-five per cent of the responses were correct. The abscissa represents the number of successive stimuli or half-oscillations, and the ordinate the positive, zero, and negative reactions in terms of percentage of adequacy. The percentage of the time, during each half-oscillation, that the subject responded positively or negatively was considered the adequacy of response. If both positive and negative reactions occurred during a half-oscillation the sum was taken as the basis for computing the percentage of adequacy. A comparison of Fig. 1, *A* and Fig. 2 will show an analogous fluctuation in perception and consequent response to oscillation slightly above and below the 50 per cent threshold. After 150 successive stimuli of this low intensity, periods of negative and zero response became more pronounced; although never continuing longer than 40–50 half-oscillations.

The rhythmic and arhythmic variation of correct response to subliminal oscillation seems to be a phenomenon analogous to that observed in vision (7) where the time between correct responses increased with a decrease in intensity of stimulation. This is congruent with progressive lengthening of refractory phase with progressive decrease in intensity of stimulation (8). There seem to be operative under these two experimental conditions alternating periods of increased and decreased excitability analogous to rebound and relative refractoriness in nervous and muscular tissue. The fluctuations in the function of the vestibular sensori-motor system, however, are much longer and more arhythmic than refractoriness and rebound in simple neuro-muscular processes, probably due to the great complexity of the system.

Experiment II

Protracted rectilinear oscillation with the subject's head, chest and abdomen strapped to the chair

Approximately the same experimental procedure was employed in rectilinear oscillation as in rotary oscillation except that a smoothly rolling platform was substituted for the rotation platform. The same driving mechanisms and analogous recording-lever systems were used.

The variability of response to rectilinear oscillation is somewhat similar to that observed in rotary oscillation, even though the ratio of sensitivity of the vestibular system to rotary and rectilinear oscillation was found to be 60 to 1 in terms of average velocity and 700 to 1 in terms of average acceleration, as stated in the previous report (2).

Fig. 3 represents the percentage of adequacy of positive and negative reactions to 100 successive stimuli or half-oscillations for Subj. RCT with oscillation of 2 cm in 3 sec, with the subject's head, chest and abdomen strapped to the chair. The amplitude and frequency were approximately at

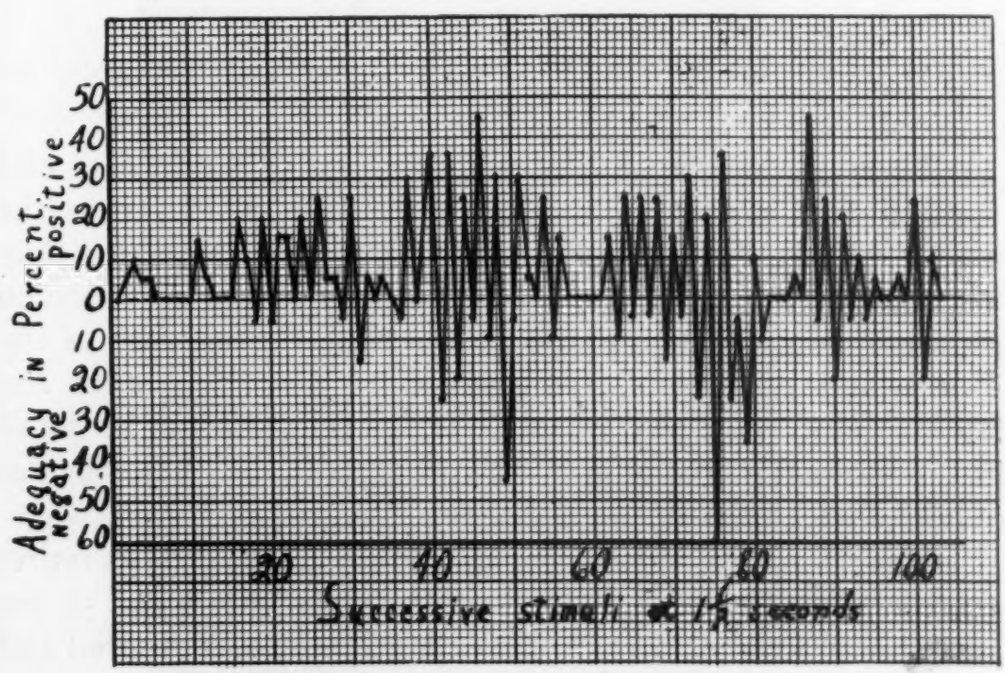


Fig. 3. Subj. RCT. Variation in percentage of adequacy of positive and negative reactions to successive oscillations of 2 cm in 3 sec for rectilinear oscillation with the subject's head, chest and abdomen strapped to the chair. Forty-six per cent of the responses were correct.

the 50 per cent threshold of RCT. The long records obtained from the other situations in rectilinear oscillation, such as standing on the platform, will not be considered here because of the complexity of the conditions.

It is evident from Fig. 3 that, here also, there are long waves of positive, zero and negative reactions. These waves occurred about every 20 to 25 stimuli or about every 30 to 35 sec. This probably indicates, as in connection with rotary oscillation with the subject at the axis, that the irritability of the vestibular system fluctuates or varies in response to repeated stimulation. This variation was not always rhythmical, but there was a sort of general response pattern to each amplitude and frequency of oscillation. The lengthening of the interval between recurring positive responses to continuous oscillation as the intensity was decreased seemed to occur quite consistently in all the records, especially with intensities near or below the 50 per cent limen. Here again the vestibular and visual systems are analogous in the lengthening of the periods of decreased irritability with a decrease in intensity of stimulation.

Experiment III

Protracted rotary oscillation with the subject at various distances from the axis of rotation

When a subject is oscillated at certain amplitudes and speeds, with the semicircular canals 200–350 cm from the axis of rotation, and one canal nearer the axis, the motion may be perceived as pure rectilinear, as pure rotary, or as motion on an arc. The measurement of the relative dominance of the rotary and rectilinear components as the distance of the labyrinths from the axis varies has been considered in detail in the previous monograph. In this report we shall consider only the effects of protracted oscillation.

It will be seen from the serial sections of a record as represented in Fig. 4, with an intensity slightly above the 50 per cent threshold, that there is evidence of periods of lowered and heightened irritability for the rotary and rectilinear components respectively. These records indicate a variability of response analogous to that given in previous sections. In

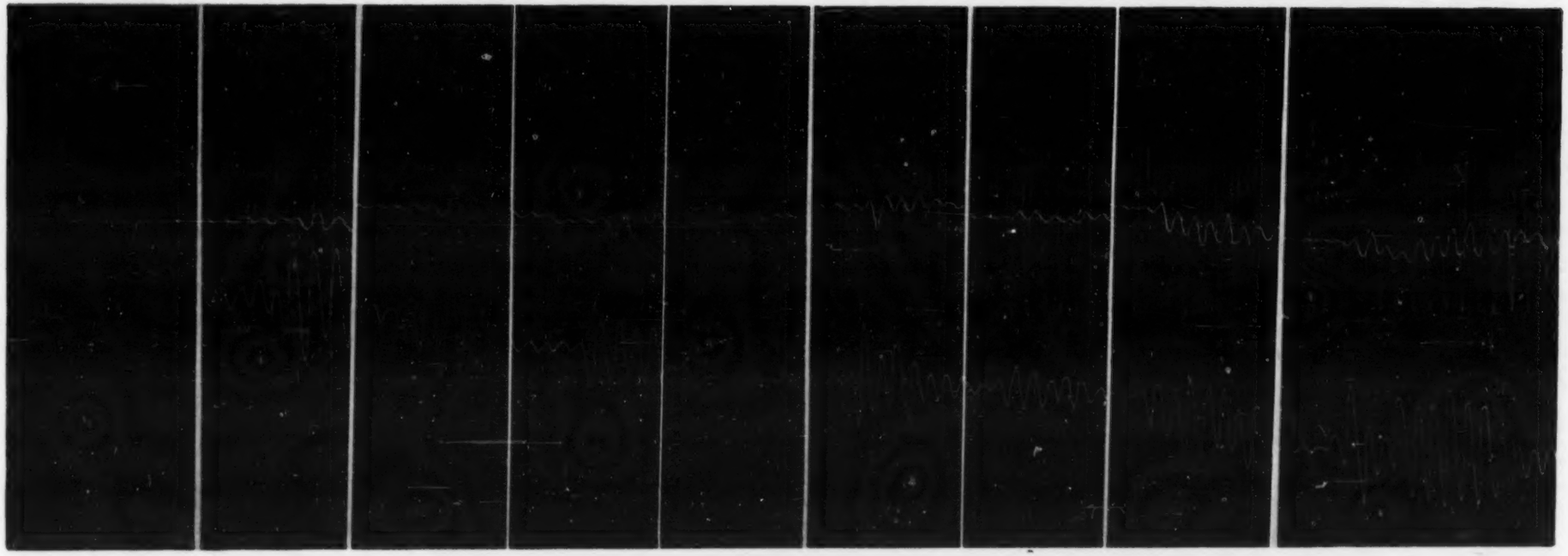


FIG. 4. Subj. RD. Sections of a record of manual compensation to the rotary and rectilinear components in rotary oscillation, 1.5 deg in 4 sec, with the subject at 217 cm from the axis of rotation. The upper compensation curves are those for the rotary component and the lower are those for the rectilinear component. From the center of one section to the center of another is equivalent to about 60 half-oscillations. The long smooth curves are the records of platform oscillation. Time recorded in sec.

addition to the rhythmic and arhythmic occurrence of lowered and heightened irritability there was evident rivalry between the rotary and rectilinear components. In the first section of Fig. 4 the rotary component predominated; but for the remainder of the record the rectilinear component was more pronounced with occasional periods of complete imperceptibility of the rotary and almost complete imperceptibility of the rectilinear component.

The alternating periods of increased and decreased excitability of the neuro-vestibular system at this amplitude and frequency for RD occurred about every 60 stimuli. As the intensity of stimulation became lower the intervals between periods of correct response increased in length, and as the intensity became greater (supraliminal) the intervals between periods of correct responses became much shorter. Furthermore, as supraliminal stimuli decreased in intensity the interval between the beginning of the oscillation and the onset of negative adaptation became shorter. That is, the system lost its sensitivity more rapidly to less intense than to more intense stimuli as indicated by the greater number of zero and negative reactions at the lower intensities.

Rivalry and competition between the two components is much more clearly indicated in Fig. 5. This record typifies the records obtained with Subj. RCT at 326 cm from the axis with a displacement of 12 cm subtending an angle of 2 deg. The phases of successive movements were 3" sec apart. The meaning of the records is obvious. A decrease in amplitude of the curves of one component is followed by an increase in amplitude of the curves of the other component, indicating rivalry between the two components, with the rectilinear slightly more pronounced in this particular record. On the whole, the two components were about equal for Subj. RCT at 326 cm from the axis. The rivalry and conflict of the rotary and rectilinear components at critical distances from the axis of rotation, the total predominance of the rotary component at the axis, and the predominance of the rectilinear component at long distances from the axis together with the great difference in vestibular sensitivity to rotary and recti-

linear oscillation strengthens the hypothesis (2) that two separate receptors function in the perception of rotary and rectilinear oscillation.

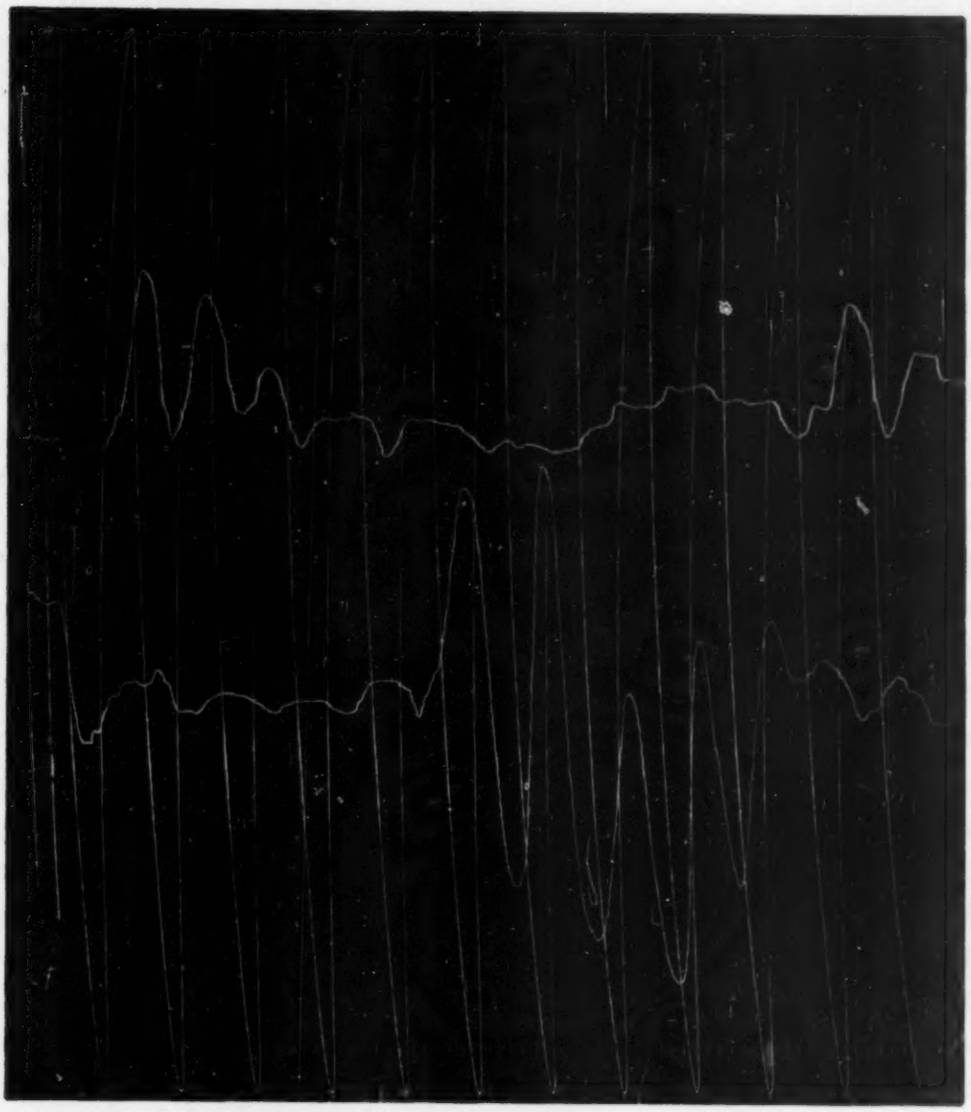


FIG. 5. Subj. RCT. Record of manual compensation to the rotary and rectilinear components in rotary oscillation, 2 deg in 6 sec, with the subject at 326 cm from the axis of rotation. The long smooth curves are records of the oscillation of the platform. The upper compensation curves are those for the rotary component, the lower are those for the rectilinear component.

EXPERIMENT IV

PROTRACTED PASSIVE INTERMITTENT ROTATION

The driving mechanism for producing regularly recurring movements of the rotation platform either clockwise or coun-

ter-clockwise at various predetermined intervals was described in detail in a report of vestibular sensitivity to intermittent rotation (3). The subject responded by pressing appropriate electric keys. The movements of the platform and the subject's response were recorded by electric markers on a smoked drum.

When a subject is passively moved intermittently either clockwise or counter-clockwise, with the canals at the center of rotation, the perception of motion varies in at least three ways. It may include intermittent movements in one direction, oscillation to the right and left, or intermittent movements in the direction opposite from that of the real movement.

Fig. 6 represents a 20-min record of response to continued intermittent counter-clockwise rotary movements of 2 deg and 2 sec duration with 2 sec between movements. This is a record of Subj. RCT, and 80 per cent of the reactions were correct. The solid irregular line represents the percentage of adequacy and kind of response to the intermittent rotary movements. The points in the solid line above zero signify positive response, while the points below zero signify negative response. The broken line above and below zero indicates perception of motion during the still-periods between the successive movements. The broken line above zero indicates that the motion was perceived to the *right;* when below, the motion was perceived to the *left.* The abscissa represents the sequence of the successive movements together with the successive intervals between movements. Each point in the broken line coincident with a point in the solid line represents a still-period immediately following that particular movement.

It is obvious from Fig. 6 that something like rivalry takes place when the subject perceived the movements and still-periods as they were, for a while, then perceived them as oscillation to the right and left, then failed to perceive the motion but perceived the still-periods as motion to the right. The latter phenomenon is a total reversal of the actual stimuli and occurred on the average 25 per cent of the time during 900 intermittent movements and still-periods (see Table I).

FIG. 6. Subj. RCT. Variation in response during alternating movement and still-periods in intermittent counter-clockwise rotation of 2 deg in 2 sec and still-periods of 2 sec between movements. Eighty percent of the responses were correct. The solid line represents the percentage of adequacy of response to intermittent rotation. The points in the solid line above zero represent positive reaction, and those below represent negative reaction. The broken line represents the percentage of the time during the alternating still-periods that the subject responded to apparent motion. The points in the broken line above zero represent apparent clockwise rotation and those below represent apparent counter-clockwise rotation.

The periodic apparent stillness during movement and the hallucinations of movement during the still-periods cannot be adequately accounted for, but seem to be analogous to the phenomenon that suggested rivalry between the right and left vestibular systems in rotary oscillation at certain critical frequencies and accelerations. This was explained in a previous section as being due to the operation of a central factor in conjunction with peripheral stimulation.

Table I gives the percentages of positive, zero and negative responses together with the direction and percentages of hallucinations of motion during the still-periods between the movements. Each movement in this case was equal to 1 deg in 2 sec (counter-clockwise) with 2 sec between movements.

TABLE I

PERCENTAGES OF POSITIVE, ZERO AND NEGATIVE RESPONSES TOGETHER WITH THE DIRECTION AND PERCENTAGES OF APPARENT MOVEMENTS DURING THE STILL-PERIODS BETWEEN ACTUAL MOVEMENTS, FOR SIX DAYS WITH 150 ALTERNATING MOVEMENTS AND STILL-PERIODS FOR EACH DAY

	Percentage of responses			Apparent movements during still-periods	
Days	Positive	Zero	Negative	Per cent counter-clockwise	Per cent clockwise
1	38	55	7	11	11
2	45	41	14	0	34
3	40	54	6	0	33
4	30	67	3	1	25
5	47	52	1	2	18
6	62	33	5	0	30
Ave.	44	50	6	2	25

It is clear from Table I that the percentages of positive, zero and negative reactions to intermittent stimuli of constant intensity vary from day to day, as do also the percentages of apparent movements during the intervals between actual movements. These data indicate again the variation in irritability of the neuro-vestibular system in response to intermittent passive rotation.

Fig. 7 shows the relation between negative response and the interval between recurring rotary movements. The abscissa represents the percentage of negative reactions or perception of motion in the wrong direction. The ordinate represents

the intervals in sec between recurring movements. For each pair of frequencies the shorter interval between recurring stimuli produced a greater number of negative responses for both subjects. (This was also true for the zero responses which are not plotted.) The average acceleration remained the same for all three pairs; but the duration of a single stimulus was 0.7 sec for the first pair, 2 sec for the second pair and 4 sec for the third. The same relationship between frequency of stimulation and negative response was true for other accelerations as well as for that shown in Fig. 7.

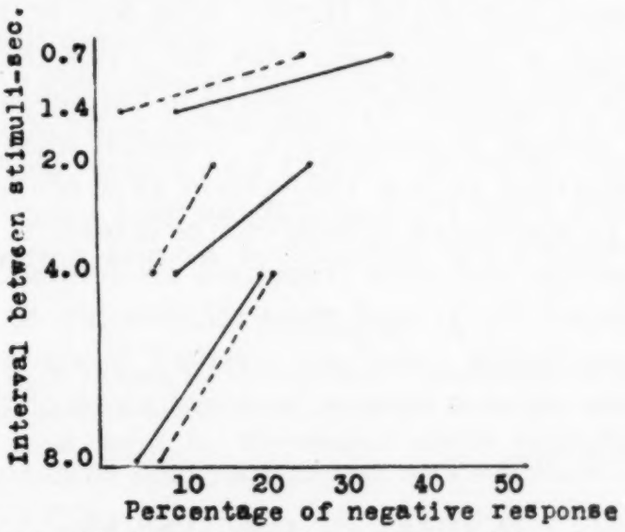


FIG. 7. Relationship between negative response and frequency of stimulation, with average acceleration constant at .02 cm per sec. Solid line for Subj. HG; broken line for Subj. RCT.

These results seem to indicate that as the interval between recurring stimuli approaches the absolute refractory period negative reactions increase.

Three conditions increase the number of negative responses; (*a*) when the oscillation or intermittent movement is sufficiently protracted (negative adaptation), (*b*) when the amplitude of oscillation decreases to and below the region of the limen and (*c*) when the interval between recurring stimuli approaches the absolute refractory period.

Whatever the explanation of this variation of response to prolonged stimulation in the vestibular and visual sensorimotor systems may be, the facts are quite clear-cut and point toward a new interpretation of response phenomena. The

alternate readiness and unreadiness of the system to respond to successive experimental stimuli of like strength, the inadequacy of the system in responding to rapidly recurring stimuli, the progressive lengthening of non-response and negative-response intervals as the intensity of stimulation is progressively reduced, the marked variation of response to like stimuli from day to day, and the interaction of central and peripheral factors, are phenomena of fundamental significance in the explanation of human adjustment. The readiness of any system to respond is probably conditioned by the interaction of one or more peripheral factors with one or more central factors, whatever their origin may be. Whether it is some change in the periphery (receptors) or in the neural center that produces a change in response to constant stimuli does not seem as important as how the system as a whole changes in responding to successive stimuli of like intensity.

The negative and zero responses as defined in this and previous reports (2, 3) and their relationship to central and peripheral excitation have not received in the tradition the attention they seem to deserve in descriptions of the stimulus-response sequence.

Summary of conclusions

1. There is a kind of rhythmic pattern in voluntary response to protracted passive oscillation and intermittent rotation of the body, indicative of rhythmic and arhythmic lowering and heightening of excitability or irritability of the neuro-vestibular system.

2. Certain rhythms are manifest in the alternate lowering and heightening of vestibular sensitivity to clockwise and counter-clockwise movements at certain amplitudes and frequencies of oscillation. The period of this rhythm varies from one experiment to another for the same individual and from individual to individual.

3. As the acceleration of protracted oscillation progressively decreased the intervals between periods of correct response increased.

4. Under prolonged stimulation near the 50 per cent

threshold the vestibular system became negatively adapted. The interval of time between the beginning of the stimulation period and the onset of the adaptation process decreased with a decrease in intensity of stimulation, but varied from day to day.

5. At irregular intervals in protracted intermittent rotation in one direction, *i.e.* clockwise or counter-clockwise, the movement periods were perceived as still-periods and the still-periods as movements in the reverse direction from the real movements. This "negative effect" was manifest in every prolonged stimulation period in intermittent rotation.

6. Negative reactions or response to perception of motion in the wrong direction increased in number under three conditions; (*a*) when the acceleration of oscillation was reduced to near threshold values and below, (*b*) when the stimulation period continued long enough, and (*c*) when the interval between recurring stimuli approached the absolute refractory period.

References

1. Travis, R. C., & Dodge, R. Sensori-motor consequences of passive rotary and rectilinear oscillation of the body, *Proc. Nat. Acad. Sci.*, 1927, 13, 843–846.
2. Travis, R. C., & Dodge, R. Experimental analysis of the sensori-motor consequences of passive oscillation, rotary and rectilinear, *Psychol. Monog.*, 1928, 38, (No. 175), 1–96.
3. Travis, R. C. Vestibular sensitivity to intermittent passive rotation of the body, *Psychol. Monog.*, (in press).
4. Newhall, S. M., & Dodge, R. Colored after images from unperceived weak chromatic stimulation, *J. Exper. Psychol.*, 1927, 10, 1–17.
5. Dodge, R. Theories of inhibition, II, *Psychol. Rev.*, 1926, 33, 182.
6. Maxwell, S. S. Labyrinth and equilibrium, II. The mechanism of dynamic functions of the labyrinth, *J. Gen. Physiol.*, 1920, 2, 349–355.
7. Travis, R. C. A phenomenon in vision similar to refractory phase, *Psychol. Monog.*, 1926, 36, (No. 168), 1–17.
8. Verworn, M. *Irritability*, 1913.

(Manuscript received June 29, 1928)

PRIMACY, RECENCY, FREQUENCY AND VIVIDNESS

BY ARTHUR JERSILD

Barnard College, New York City

Each of the factors named in the title has been subjected from time to time to an experimental study. Extensive investigations have been made on the effect of repetition in learning a new performance, on the influence of serial position in memorizing an assignment and on the value of certain forms of vividness in strengthening the fixation of presented items. A recent study by Hollingworth [1] provides data on the relative strength of all of these factors when they operate collectively within a single array of paired associates under visual presentation for immediate recall.

The present investigation raises the following question. What is the relative effectiveness of various degrees and forms of primacy, recency, frequency and vividness in determining the impressiveness of items contained in a narrative account? To this query the experimental literature yields only an indirect answer. Meaningful material has enjoyed but little prominence in the investigation of these factors, due largely, no doubt, to the hazards entailed by its use. The present study is designed to cope with the sources of error that inhere in the use of meaningful material and to attack the problem here raised by means of a procedure controlled to the fullest extent within the experimental method employed. A description of the experiment follows.

The material presented vocally to the subjects was of a narrative order, consisting of a biographical account of a fictitious character. This biography contained seventy distinct statements of fact, each of which could be separately scored on a test for immediate recall. In a given presentation of the material the following factors and conditions were under observation:

Primacy;—first three statements (taken to represent three degrees)

Recency;—last three statements

[1] H. L. Hollingworth, *Psychology; its facts and principles*, Appleton, 1928, 243–246.

Frequency;—10th statement immediately repeated (two concentrated repetitions)
60th statement immediately repeated (two concentrated repetitions)
35th statement repeated after the 40th (two distributed repetitions)
11th statement repeated after the 60th had been twice presented (two widely distributed repetitions)
One statement was given 3, another 4, and still another 5 distributed repetitions

Vividness;—"Now get this" (verbal emphasis preceding presentation of statement)
"Did you notice that?" (retroactive verbal emphasis)
Increased loudness (voice raised above customary amplitude)
Gesture (arm thrown up in conventional gesture while statement was being presented)
Bang (fist brought violently down upon the desk while last word of statement was being spoken)
Spoken very slowly (speed of articulation very much retarded in presenting statement)
Pause (interval equivalent to time necessary for a repetition of the statement allowed to elapse before next item was presented).

In addition to these factors, the following positions in the exercise were also scored;

'Middle neutral' = All statements falling within range from number 25 to 45, presented once and not subjected to vividness

'Normal' = All statements intermediate between primacy and recency, presented once and not subjected to vividness

Ten different arrangements of the material were used with ten groups of subjects, comprising a total of 253 persons, all collegiate students. The experimenter simply announced to each group that an oral exercise would be presented and that a test for recall would immediately follow. In presenting the material, the experimenter made use of a typewritten sheet containing the statements and the necessary cues to repetition and vividness. Following the presentation, the subjects were told to reproduce in writing as many statements as they could remember. In scoring the papers the score for each statement was recorded in terms of the number of correct reproductions shown for it within the group. From this record were obtained two separate scores for each experimental factor.

A description of the scoring methods demands first a comment on the controls required in a study of this kind. A critical source of error in the use of meaningful material lies in the fact that not all statements in a narrative account will have exactly the same memorial value.[2] To equate the value for memory of a large number of

[2] This term is used simply to denote the empirical fact that some items are recalled more readily than others. Thus words have a higher memorial value than nonsense syllables.

statements is no easy matter, since the ease with which a given item is memorized will be a function not only of its peculiar character but also of its serial position in the exercise and the context in which it is placed. The first of these variables can never be fully segregated from the remaining two. Nevertheless it is possible, where many groups of subjects are employed, so to rotate the materials that no experimental factor will be favored unduly by differences in the memorial value of the various statements. This procedure was adopted in the present experiment.

With each of the experimental groups a special arrangement of the materials was used. As a result, a particular statement was used in connection with each experimental factor in each of the various presentations. For example, ten unlike statements occupied the first position in the exercise as presented to the ten separate groups of subjects. The score for the first degree of primacy, accordingly, was derived from a wide variety of items. Moreover, the rotation of the items provided that each statement which, in a given presentation, occurred in connection with a certain experimental factor would in other instances occur in connection with other experimental factors, and in still other instances appear in a "middle neutral" position.

The immediate score for a given experimental factor, according to this procedure, consisted simply in a record of the number of correct reproductions of the statement in connection with which it was used. This record will hereafter be referred to as the *numerical* score. In the separate groups the numerical score will be influenced to some degree by differences in memory-value of the various statements. In the experiment as a whole it will represent the record made by a given experimental factor when used in connection with a wide number of varying statements, so rotated as to equate the matter of differences in memory-value.

The second of the two scores obtained for each experimental factor was derived by a special scoring method. This method, which yielded what will be referred to as the *percentage* score, was designed as a further precaution against differences in memorial value. By means of it, the recall-record for a given experimental factor when presented in connection with a given statement was calculated in terms of the score which obtained for that same statement when appearing in a "middle neutral" position with other groups of subjects. By way of illustration: A given statement occupies the first position (primacy) in the exercise as presented to a group of 20 subjects. It is reproduced by 15 on the test for recall. Its numerical score is 15; its recall-ratio, 15: 20. This same statement, when appearing in a middle neutral position with other groups, comprising 100 subjects, is reproduced by 50. Its recall-ratio here is 50:100. The resulting *percentage* score for the first degree of primacy in the group above, according to the method here employed, is 15:20::50: 100, or 150. In each instance of the application of this method the standard memory-value of a given statement was represented by its ratio of correct reproductions when appearing in a middle neutral position.

The results obtained from each of the ten experimental groups as determined by the two scoring methods are shown in Tables I and II.

Table I gives the numerical scores for each of the factors, as well as the average (normal) score for all statements belonging to the exercise and not subjected to any experimental device.

TABLE I

NUMERICAL SCORES

Group	A	B	C	D	E	F	G	H	I	J	Total
No. of cases	21	43	46	20	10	22	26	19	24	22	253
Devices											
Normal	10.1	20.2	19.8	9.6	4.2	9.1	8.3	7.6	9.3	7	105
Primacy											
First statement	20	32	30	19	9	16	20	13	11	22	192
Second statement	19	30	37	15	6	7	16	12	17	4	163
Third statement	14	13	33	18	8	14	5	4	16	8	133
Recency											
68th statement	10	15	8	18	1	7	20	4	19	19	121
69th statement	15	17	9	11	7	5	21	1	21	19	126
70th (last) statement	19	9	25	12	9	9	22	10	14	10	139
Frequency											
2 concentrated repetitions											
10–10	10	11	35	4	6	10	20	7	2	14	119
60–60	16	12	19	16	7	14	20	5	9	8	126
2 distributed repetitions											
35–40	20	27	29	18	3	10	15	11	10	20	163
11–60	20	38	20	17	6	19	18	11	10	16	175
3 repetitions	21	37	37	....	8	17	....	14	22	17	211
4 repetitions	21	40	41	20	10	18	26	19	22	17	234
5 repetitions	21	39	46	19	9	22	26	19	23	20	244
Vividness											
"Did you notice...?"	16	38	40	7	8	3	10	11	9	16	158
Slow	5	9	9	10	9	4	6	10	3	17	82
Bang	14	16	26	7	7	6	11	18	9	7	121
Gesture	2	14	38	3	5	9	21	10	5	13	119
Loud		23	22	7	5	14	15	6	5	16	123
Pause	9	35	32	10	1	9	10	13	15	9	143
"Now get this"	11	41	37	15	5	20	21	7	14	5	176

Table II gives the corresponding percentage scores. The standard or middle neutral positions, in this case, have a constant value of 100 by virtue of the scoring method employed.

The last column in each table gives the results for all the experimental groups taken as a whole. In Table I these results consist of the arithmetical total of all the separate group-scores. In Table II the total percentage score was derived from a composite of all the ratios from which the separate scores of each group were obtained.

TABLE II

PERCENTAGE SCORES

Group	A	B	C	D	E	F	G	H	I	J	Total
No. of cases	21	43	46	20	10	22	26	19	24	22	253
Devices											
Middle Neutral	100	100	100	100	100	100	100	100	100	100	100
Primacy											
First statement	138	164	283	300	195	228	131	181	123	252	175
Second statement	221	95	112	181	135	399	184	160	100	81	163
Third statement	200	151	160	134	137	186	90	49	159	138	135
Recency											
68th statement	210	260	105	180	38	77	107	62	111	144	123
69th statement	180	178	152	275	192	60	91	50	100	121	119
70th (last) statement	177	121	186	165	190	107	125	168	66	212	128
Frequency											
2 concentrated repetitions											
10–10	310	81	142	82	148	113	111	98	106	72	116
60–60	147	147	156	123	164	142	153	94	216	166	139
2 distributed repetitions											
35–40	133	153	219	228	78	174	159	136	119	180	162
11–60	231	151	308	384	169	122	119	104	185	102	167
3 repetitions	222	191	253	...	505	184	...	196	147	207	197
4 repetitions	268	230	151	272	144	284	311	268	315	446	246
5 repetitions	284	310	183	441	698	238	222	426	501	646	315
Vividness											
"Did you notice . . . ?"	231	131	261	229	123	103	103	144	199	89	154
Slow	138	95	75	86	150	49	30	95	39	154	79
Bang	156	103	150	113	97	77	108	132	62	90	115
Gesture	122	108	115	86	256	90	98	278	55	112	118
Loud		88	155	149	100	127	163	119	60	173	126
Pause	137	111	120	292	50	115	149	120	284	67	143
"Now get this"	247	187	133	340	213	139	112	363	130	177	191

As might well be expected, the magnitude of the scores shown in Tables I and II for each experimental factor fluctuates considerably from group to group. The determinations tend toward the same general direction, however, and a clear differentiation of the strength of the various factors is revealed by the columns showing the results from the experiment taken as a whole. A high degree of correspondence obtains between the results as determined by the two separate scoring methods.

In Table III the various factors are arranged in order of merit according to their effectiveness as determined by the two scoring methods.

TABLE III

ORDER-OF-MERIT ARRANGEMENT OF THE VARIOUS DEGREES AND FORMS OF PRIMACY, RECENCY, FREQUENCY AND VIVIDNESS

(10 groups; 253 cases)

Numerical Score		Percentage Score	
5 repetitions	244	5 repetitions	315
4 repetitions	234	4 repetitions	246
3 repetitions	211	3 repetitions	197
Primacy; first degree	192	"Now get this"	191
"Now get this"	176	Primacy; first degree	175
2 distributed repetitions (11–60)	175	2 distributed repetitions (11–60)	167
Primacy; second degree	163	Primacy; second degree	163
2 distributed repetitions (35–40)	163	2 distributed repetitions (35–40)	162
"Did you notice that?"	158	"Did you notice that?"	154
Pause	143	Pause	143
Recency; last statement	139	2 concentrated repetitions (60–60)	139
Primacy; third degree	133	Primacy; third degree	135
Recency; second from last statement	126	Recency; last statement	128
2 concentrated repetitions (60–60)	126	Loud	126
Loud	123	Recency; third from last statement	123
Bang	121	Recency; second from last statement	119
Recency; third from last statement	121	Gesture	118
Gesture	119	2 concentrated repetitions (10–10)	116
2 concentrated repetitions (10–10)	119	Bang	115
Normal	105	Middle Neutral	100
Slow	82	Slow	79

The two separately determined orders of scores shown in Table III are in close agreement as to the main outcome. The deviations in rank which occur are of a minor character and do not point to inconsistent results.

The Table speaks for itself in answer to the question raised at the beginning of this study. Frequency, to the extent of three or more repetitions, is the most effective device; next in order come the first degree of primacy and the first degree of vividness in the form of prior verbal emphasis; then comes the device of two distributed repetitions; and following this, various conditions of primacy, vividness, repetition and recency.

Discussion of Results

Frequency. The high scores resulting from three or more repetitions are not surprising. Frequent distributed repetition effects not only the benefit of exercise but also the advantage of some degree of primacy and recency as well as implied emphasis.

Worthy of note is the discrepancy between the magnitude of the frequency-scores as determined by the two scoring methods. The numerical scores reveal only a slight difference between the values of three, four and five repetitions. The percentage-scores, on the other hand, accentuate this difference more sharply. This discrepancy arises in part from the fact that a test for immediate recall, such as that employed in the present experiment, cannot provide an adequate measure of the value of frequent repetition. The numerical score for a given item is limited by the number of subjects within the group. No indication is given of the effect of repetition carried beyond the point necessary to bring about universal recall. To illustrate: A statement is repeated three times with a given group of 20 subjects; the result is unanimous recall. The same statement is repeated five times with another group of like size; again unanimous recall. The numerical scores for both frequencies are the same, and five repetitions seem no more advantageous than three.

In the above illustration the percentage-score for both frequencies would also be the same. But in the case where unlike statements, neither of which scores universal recall, are used with the two frequencies, and the statement which is repeated five times has a lower memory value than the other, the effect of five as compared with three repetitions will stand out more clearly.[3] E.g. a statement is repeated three times with a group of 20 and yields a score of 19; another statement is repeated five times and yields a score of 19. The former statement when appearing in a middle neutral position with other groups was recalled by 50 of a total of 100 subjects;

[3] The experimenter deliberately tampered with the order of rotation in two instances by choosing for five repetitions statements which in previous presentations had scored relatively very low. This procedure contributed to the difference between the magnitude of the numerical and the percentage scores.

the latter, when similarly presented, was recalled by 30. The percentage-score for the former in this case is 190 (19: 20:: 50: 100), and that for the latter is 316, whereas the numerical scores for both frequencies had been the same. According to the illustration here presented, which is typical of actual results, the lower the memory-value of a given item the greater will be the relative value of increased repetition as revealed by the percentage-score.

Both scoring methods indicate the "law of diminishing returns" for frequency. Added frequency increases the effectiveness of recall; but not in direct proportion to the number of repetitions. No final statement of this relationship can be made, however, due to the limitations of the scoring methods in immediate recall.

Spaced and Unspaced Repetition. A striking result appears in the relative value of two repetitions when given in immediate succession and when separated by intervening items. The 11th statement was presented a second time after the 60th had been read twice. Its respective scores are 175 and 167. The middlemost (35th) statement was repeated after the 40th; its scores are 163 and 162. The more widely distributed repetition scores somewhat higher; but the difference is slight and may be due to the advantage of some degree of primacy and recency which obtains for it. In contrast with these items are the two cases of concentrated repetition. The 10th and the 60th statements were presented twice in succession. The scores for the former are 119 and 116; for the latter, 126 and 129.[4] These scores are decidedly lower than those for spaced repetition. There is distinct evidence for the superiority of distributed as compared with concentrated repetition.[5]

Primacy and Recency. Another outstanding result is the

[4] It appears, incidentally, that two successive repetitions near the end of an exercise are more effective than repetitions near the beginning.

[5] This result in immediate recall is concordant with many studies of economica distribution of effort in the mastery of performances demanding extended practice. The prevailing, although not universal, outcome has been that economy of time and effort is effected by distributing the practice with intervals. For investigations bearing upon this problem and reviews of previous studies see C. J. Warden, The distribution of practice in animal learning, *Comp. Psychol. Monog.*, 1923, 3; L. A. Pechstein, Massed vs. distributed effort in learning, *J. Educ. Psychol.*, 1921, 12, 92–97.

high score shown for primacy. The first position in the exercise has the advantage over two distributed repetitions; and as compared with the strongest degree of recency it stands far in the lead.[6] Indeed, the ultimate degree of recency appears to be no more effective than the third degree of primacy. Of all the devices here under investigation primacy stands out as prepotent: to surpass the effect of primacy it is necessary to expend the time involved in giving three or more repetitions, or to resort to time-consuming vividness devices. From this study it appears that the first statements in a verbal discourse make decidedly the strongest impression.

The question as to the relative strength of primacy and of recency has been variously answered. Ebbinghaus found that the first three members of series of nonsense syllables required far less prompting than did the last three. Robinson and Brown, in a study involving memorization of nonsense syllables, and Warden, in a study which employed the stylus maze, also found primacy to be more advantageous. In investigations reported by Calkins, Bigham, Owen, and Welsh and Burnett the evidence favors recency. (For review and discussion of these studies see Robinson and Brown, The effect of serial position upon memorization, *Amer. J. Psychol.*, 1926, 37, 538 ff.) Hollingworth (*op. cit.*) found that the ultimate degree of recency surpassed the first degree of primacy, whereas the penultimate and antepenultimate degrees of recency scored slightly lower than the corresponding primary positions. Husband, in a study of learning on the finger maze (*J. Gen. Psychol.*, 1928, 1, 15–28), found that the first section was learned more quickly than the last; and, in a study which dealt not with learning but with the rôle of order of presentation in persuasion, Lund (*J. Abn. & Soc. Psychol.*, 1925, 30–37) found that the first of two opposing arguments on a controversial subject had the advantage in persuasiveness. Of the various investigations here discussed, the present alone relates the problem of primacy and recency to the recall of narrative material.

The superiority of primacy, as indicated so emphatically in the present study, may be accounted for on various grounds. Previous writers have pointed out that the first position benefits from the absence of proactive associative interference, which will arise as a cumulative deterrent in subsequent parts of the exercise, and from the fact that the first items lend themselves to rehearsal while later items are being presented. But in a similar vein it might be argued that recency should have the advantage, since it escapes the supposedly harmful effects of retroactive associative interference, and, as Owen pointed out, it may profit from the fact that the time-interval separating the presentation and the recall is less for items in the final position.

On these points more might be said. The present writer inclines to the view that

[6] A further check on this result was obtained from the experimental data. Each of four statements occupied, at various times and with different groups, the first position in the exercise; and these same statements, in other presentations, occupied also the final or most recent position. Reduced to a common denominator, the score for these statements in the primary position was 128, and in the final position 100.

the advantage of primacy arises in part also from a difference in the degree of active attention devoted to a discourse at various stages of its presentation. The first statements will have a stronger command of the subject's interest, curiosity and active participation than items which follow. To give sustained attention over an extended period is at best a difficult matter unless the presented material is intrinsically very interesting and moves on toward a climax.

Vividness. The results show that all the vividness devices employed in this study, except that of speaking very slowly, serve as positive aids to recall. Since all the devices were used with unselected statements and were inserted at different points in the exercise, to equate the factor of position, an interesting comparison can be made of their relative value as modes of impressiveness.

It is rather curious that the device of speaking very slowly should fare so poorly. The score for this device falls far below that for normal, unemphasized items. To present a matter in slow deliberate tones seems to hinder rather than to facilitate the fixation of the material so conveyed.

The expedient of making a gesture and that of banging the desk have, in general, a beneficial effect, as shown by the total scores. But a glance at Tables I and II will show that both of these forms of gesticulation fell below the score for normal and middle neutral positions in four out of the ten instances. This fluctuation in the separate group results indicates that these devices may at times operate as distractions rather than as aids.

The device of loudness, effected by raising the voice above the accustomed amplitude, surpasses the three 'emphasis' designs already discussed. Since all other items were presented with sufficient intensity to be well above the threshold for hearing the present results do not give a comprehensive indication of the effect of varying degrees of loudness. Yet it is clear that the single accented statement has an advantage over those presented at the normal amplitude.

Even more effective is the device of making a pause. This expedient consumed the same amount of time as was required by that of speaking very slowly and that of repeating the statement a second time. In view of this fact, interesting comparisons can be drawn. The scores for a pause are 143

and 143; those for two concentrated repetitions are 119 and 116 in one case, 126 and 139 in the other. The pause is clearly more beneficial than a second immediate presentation. This result tends to corroborate the view that a certain amount of active rehearsal is carried on by the subjects while reacting to the presentation of memory materials. The rehearsal which takes place during an interval of delay is more advantageous than the sheer primary effect of an immediate repetition. The scores for two distributed repetitions, however, are higher than those for a pause; so it appears that the revival of an impression after the elapse of an interval of time is more profitable than the opportunity to review the item immediately after its initial reception. The extremely low score for the device of speaking slowly as compared with that of making a pause no doubt arises in part from the fact that no active review of a statement can take place until the last word has been spoken, since not until then will the content of the statement be known. This interval of delay cannot be utilized to advantage; time is lost, and nothing is gained.

Most effective of all is the device of verbal emphasis. Proactive emphasis ("Now get this") is so potent as to be tied with the first degree of primacy for a rank second only to that of three or more repetitions. Retroactive emphasis ("Did you notice that?") scores higher than all other remaining 'vividness' devices, and is superior to two concentrated repetitions. The relative strength of the two verbal designs (proactive emphasis scored 176 and 191; retroactive, 158 and 154) indicates that to call attention to an item prior to its presentation is more effective than to lay stress upon it after it has been spoken.

General Summary

The present investigation was designed to test the relative effectiveness of various degrees and forms of primacy, recency, frequency and vividness in immediate memory for meaningful material. The material consisted of seventy narrative statements, presenting a biographical sketch of a fictitious character. Each statement was scored separately on a test for

recall. Ten groups of subjects (253 college students) were employed. To overcome differences in memory-value for the several statements the method of rotation of the items in going from one experimental group to the next was used; and, as a further precaution, a special scoring method was devised by means of which the score for a statement when used in connection with an experimental factor was calculated in terms of the score which obtained for that same statement when occurring in a position at the middle of the exercise and not subjected to any experimental device.

The most succinct summary of the results can be found in the order-of-merit arrangement of the various factors shown in Table III. In the order of their effectiveness, the devices here studied range themselves as follows; 5, 4, and 3 distributed repetitions; first degree primacy, and proactive verbal emphasis ("Now get this"); two widely distributed repetitions; second degree primacy; two distributed repetitions, separated by five intervening items; retroactive verbal emphasis ("Did you notice that?"); a pause; final degree of recency, two concentrated repetitions falling near the end of the exercise, and third degree primacy; increased loudness; penultimate and antepenultimate degrees of recency; a gesture, and banging the table; two concentrated repetitions occurring near the beginning of the exercise; normal statements appearing without relationship to any experimental device; the device of speaking very slowly.

The following additional facts also emerge from the general results.

The benefit arising from increased frequency does not increase in direct proportion to the number of added repetitions.

The lower the memorial value of a given item, the greater will be the relative benefit effected by increased repetition.

Two repetitions are decidedly more effective when an interval elapses between the first and second presentations than when the item is presented twice in immediate succession.

Primacy stands out as far superior to recency as an aid to the recall of meaningful material. (It is suggested in

partial explanation of this fact that the first statements have the advantage of a higher degree of active attention, interest and curiosity than do items which occupy a middle or final position.)

Artificial emphasis in the form of a gesture and of a bang upon the table with one's fist while speaking serves as an aid to fixation; but these devices have a relatively low value, and at times may operate as distractions rather than as aids.

To pause for an interval equivalent to the time that would be required for a second presentation of an item is more efficacious than to give an immediate repetition of the item, but not as effective as to repeat the item after the lapse of a period of time.

The device of speaking very slowly operates as a hindrance to fixation and recall.

The most effective form of vividness in vocal presentation is verbal emphasis by means of accessory comments which direct the listener's attention to a specific item.

(Manuscript received July 4, 1928)

THE EFFECT OF OVERLEARNING ON RETENTION

BY WM. C. F. KRUEGER

Psychological Laboratory, University of Chicago

This experiment is concerned with the following problems. (1) As the degree of learning is varied from 100% to 200 %, will the degree of retention vary proportionally, *i.e.* will 50% overlearning increase the amount retained by 50% or by some other proportion? (2) Will the relation between the degree of retention and the degree of learning vary with the interval between learning and recall? For example, if 50% overlearning increases retention by 40% after a one-day interval, will this latter percentage increase or decrease with the length of the interval?

Luh [1] obtained results bearing upon these problems. The subjects, college students and one instructor, memorized series of nonsense syllables of 12 each. The lists were presented on a memory drum, each word being exposed for two seconds. Only one degree of overlearning was used, namely 150% learning. The intervals between learning and recall were 4 hours, 1 day and 2 days. Retention was tested by the methods of unaided written reproduction, recognition and reconstruction. The increase of retention was always less than the degree of overlearning. The ratio of retentive increase to the degree of overlearning decreased with the interval, and in some cases overlearning even proved detrimental. For example, when retention was measured by written reproduction, the 4-hour interval showed an increase of 17.1%, while the 1-day interval gave an actual decrease of 7.1%, and the 2-day interval showed a decrease of 10.6%. The results were approximately the same for all three methods of measuring retention.

[1] C. W. Luh, The conditions of retention, *Psychol. Monog.*, 1923, 31, (no. 142), p. 44.

The present experiment was designed to supplement and to extend Luh's work by employing two degrees of overlearning and a wider range of intervals. Our experimental conditions differ from Luh's in the following respects. Instead of series of 12 nonsense syllables we used lists of 12 monosyllabic nouns. We had 2 degrees of overlearning, 50% and 100%. The range of intervals in our experiment was 1, 2, 4, 7, 14 and 28 days. Retention was tested (1) by anticipatory verbal recall and (2) by the 'saving method.'

A list of words was presented by means of a memory drum at the rate of two seconds per word. S was permitted to use any method of memorizing except that of writing down the words. The usual anticipatory method of verbal recall was employed to test the degree of learning, but the anticipatory test was given in alternate trials instead of in every trial, as is usual. By 100% learning we mean the degree or stage of perfection at which S was first able to anticipate correctly all the words in the list in a single presentation. To obtain 50% overlearning the presentations were continued until the number was increased by one-half of the number of trials required for the 100% degree of mastery, and 100% overlearning by giving twice the number of trials necessary just to learn the list. If, for example, 10 trials were needed to learn a list 100%, 5 more was the number arbitrarily set for 50% overlearning; if 12 trials were necessary, 6 more were added, etc. Only one new list was learned on any one day.

Different groups of subjects were utilized for the various intervals; but the lists employed were the same throughout. For each interval the same group was used for the three degrees of learning. Two methods were employed to eliminate the possibility that the differences between the three learning and retention scores might be due to practice. (1) All Ss were first required to memorize four practice-lists before being tested; (2) one-half took the three conditions in the order of 100%, 150% and 200% learning, while the other half took them in the reverse order of 200%, 150% and 100% learning. To avoid the possibility that the differences

in retention were due to differences in the difficulty of the lists, each of 20 Ss learned a different list for a given degree of mastery. Thus the average for each condition was based upon the retention scores for twenty lists. There was one exception. For each degree of learning with a one-day interval, the averages were computed from 40 retention scores, or 2 scores from each of the twenty lists. After the specified interval, the subjects were required to relearn the lists up to a 100% stage of mastery. The subjects were tested by the anticipatory method of verbal recall on the odd-numbered trials. This gave us two measures of retention, (1) the number of words correctly anticipated on the first presentation, and (2) the percentage of saving based upon learning and relearning scores.

In Table I is found, for each of the eighteen conditions, the average number of trials necessary (1) to learn and (2) to relearn a list. Column three states the average number of

TABLE I

AVERAGE NUMBER OF TRIALS TO LEARN AND TO RELEARN A LIST

Interval (days)	Degree Learn'g (%)	Trials req'd to Learn a List (av)	Trials for 100% Learn'g (av)	SD for 100% Learn'g Score	PE for 100% Learn'g Score	T'ls to Rel'n a List 100% (av)	SD for Relearn'g Score	PE for Relearn'g Score
1	100	4.25	4.25	1.34	.14	3.20	1.01	.11
1	150	7.00	4.40	1.36	.14	2.73	.74	.08
1	200	8.86	4.43	1.22	.13	2.30	.75	.08
2	100	4.40	4.40	1.24	.19	3.65	1.06	.16
2	150	7.40	4.85	1.35	.20	3.15	.92	.14
2	200	9.60	4.80	1.44	.22	2.65	.65	.10
4	100	4.55	4.55	1.12	.17	4.30	.96	.14
4	150	7.30	4.70	1.27	.19	3.25	.92	.14
4	200	9.20	4.60	1.32	.20	3.00	1.00	.15
7	100	4.45	4.45	1.94	.29	4.20	1.57	.24
7	150	6.30	4.15	1.28	.19	3.00	.55	.08
7	200	9.10	4.55	1.66	.25	3.05	1.16	.17
14	100	4.40	4.40	1.01	.14	4.30	1.10	.16
14	150	6.95	4.50	1.20	.18	3.45	.74	.11
14	200	8.50	4.25	1.04	.16	3.05	.74	.11
28	100	4.65	4.65	1.49	.22	4.55	1.66	.25
28	150	7.40	4.85	1.11	.17	3.80	.93	.14
28	200	9.50	4.75	1.55	.23	3.50	1.18	.18

trials necessary to memorize a list to the specified degrees of learning. The fourth column gives the average number of trials required to attain a 100% degree of learning. The seventh column records the average number of trials required to relearn each list. All averages are based on twenty measures with the exception of those for the one-day interval which are based upon forty scores. The other columns give the measures of variability, such as the S.D.'s and P.E.'s for each average.

By inspection it may be seen that the learning scores, based upon 100% learning, were approximately the same for the eighteen conditions. Thus any differences in the amounts retained cannot be accounted for by differences in the learning scores.

The retention scores are given in Tables II and III. The verbal-recall scores which are found in the third column of Table II represent the average number of words recalled for

TABLE II

AVERAGE VERBAL RECALL SCORE AND RELIABILITY OF THE DIFFERENCE BETWEEN OBTAINED AVERAGES

Interval (days)	Degree Learn'g	No. Words Recalled (av) (%)	SD for Verb. Recall Score	PE for Verb. Recall Score	Reliab'y of Diff. bet. Means for 100% and 150% Learning	Reliab'y of Diff. bet. Means for 150% and 200% Learning
1	100	3.10	2.30	.23		
1	150	4.60	2.43	.26	4.20	
1	200	5.83	2.86	.30		6.97
2	100	1.80	1.72	.26		
2	150	3.60	2.18	.33	4.30	
2	200	4.65	2.22	.33		6.73
4	100	.50	.81	.12		
4	150	2.05	1.88	.28	5.99	
4	200	3.30	2.26	.34		8.56
7	100	.20	.40	.06		
7	150	1.30	1.27	.19	5.48	
7	150	1.65	1.42	.21		6.50
14	100	.15	.36	.05		
14	150	.65	.65	.10	4.45	
14	200	.90	.77	.12		5.87
28	100	.00	.00	.00		
28	150	.25	.43	.07	3.80	
28	200	.40	.49	.07		5.40

each condition. In the next two columns of the same Table are the S.D.'s and P.E.'s for the corresponding averages. The last two columns give the ratio of the difference between the two obtained means to the P.E.(diff.). All values above 4 indicate a statistically significant difference between the two respective averages.

TABLE III

AVERAGE PERCENTAGE RETAINED AS MEASURED BY THE SAVING METHOD

Interval (days)	Degree Learn'g (%)	Retained as Meas'd by Sav. Method (av %)	SD for Retention Score	PE for Retention Score	Reliab'y of Diff. bet. Means for 100% and 150% Learning	Reliab'y of Diff. bet. Means for 150% and 200% Learning
1	100	21.73	27.97	2.98		
1	150	36.15	22.67	2.42	3.76	
1	200	47.10	24.62	2.64		6.34
2	100	13.40	23.97	3.62		
2	150	33.45	14.80	2.22	4.72	
2	200	42.05	14.10	2.13		6.83
4	100	3.40	20.12	3.03		
4	150	29.75	14.79	2.23	6.99	
4	200	32.30	25.50	3.20		6.53
7	100	1.75	21.21	3.20		
7	150	23.15	18.78	2.83	5.01	
7	200	27.55	24.14	3.64		5.32
14	100	1.65	14.14	2.13		
14	150	20.80	14.24	2.15	6.26	
14	200	25.45	21.28	3.21		6.48
28	100	1.50	20.32	3.06		
28	150	20.50	16.09	2.43	4.86	
28	200	25.10	14.53	2.19		6.53

Table III states the average retention-scores for all conditions, as derived by the saving method. These values were computed by the usual formula from the 100% degree of learning and the relearning scores of Table I. Column three gives the average percentage retained for each degree of learning and for the various intervals. The S.D.'s and P.E.'s for these averages are in the next two columns. The last two columns give the ratio of the difference between the respective means to the P.E.(diff.).

The retention scores of Tables II and III show that for every interval the highest amount retained was for 100%

overlearning, while 100% learning always gave the least score. The ratios of the differences between two obtained means to their P.E.(diff.) express a statistically valid difference between the two respective retention scores without a single exception.

In order to discover whether the relation between the degree of learning and the degree of retention varies with the interval between learning and recall, we computed the ratios between the retention-scores for 100% learning and 150% learning and the ratios of the retention-scores for 150% learning and 200% learning. The respective degrees of learning stand in the ratios of 1 : 1.5, and 1 : 1.33. By dividing the retention-scores for each interval by the retention-scores for the lesser degree of learning we get the corresponding ratios of retention. For example, according to Table II, the retention-scores for 100% and 150% learning for the one-day interval stand in the ratio of 3.10 : 4.60, and the retention-scores for 150% and 200% learning are in the ratio of 4.60 : 5.83. By dividing the first ratio by 3.10 and the second ratio by 4.60 (the retention-scores for the lesser degree of learning) we obtained the simplified ratios of 1 : 1.48 and 1 : 1.27. These ratios mean that an increase of learning from 100% to 150% gave a corresponding increase in retention of 48%, while increasing learning by an additional 33⅓% (from 150% to 200%) increased retention only by 27%. Tables IV and VI give the two series of ratios for the

TABLE IV

RATIO OF DEGREE OF LEARNING AND CORRESPONDING RATIOS OF RETENTION FOR 100% AND 150% LEARNING

Ratio of Learning	Ratios of Retention as Measured by Verbal Recall *Interval (days)*					
	1	2	4	7	14	28
1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.50	1.48	2.00	4.10	6.50	4.33	Infinity

TABLE V

RATIO OF DEGREE OF LEARNING AND CORRESPONDING RATIOS OF RETENTION FOR 100% AND 150% LEARNING

Ratio of Learning	Ratios of Retention as Measured by the Saving Method *Intervals (days)*					
	1	2	4	7	14	28
1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.50	1.66	2.50	8.75	13.23	12.06	13.67

TABLE VI

RATIO OF DEGREE OF LEARNING AND CORRESPONDING RATIOS OF RETENTION FOR 150% AND 200% LEARNING

Ratio of Learning	Ratios of Retention as Measured by Verbal Recall *Intervals (days)*					
	1	2	4	7	14	28
1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.333	1.27	1.29	1.61	1.27	1.38	1.60

TABLE VII

RATIO OF DEGREE OF LEARNING AND CORRESPONDING RATIOS OF RETENTION FOR 100% AND 150% LEARNING

Ratio of Learning	Ratios of Retention as Measured by the Savings Method *Intervals (days)*					
	1	2	4	7	14	28
1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.33	1.30	1.26	1.08	1.19	1.22	1.22

verbal recall scores. By the same procedure we computed the ratios of retention for the scores derived by the 'saving method.' These ratios are found in Tables V and VII. To illustrate the relative efficacy of overlearning for the various intervals, we see that, as stated in Table IV, 50% overlearning increased retention 48% for the one-day interval, 100% for the two-day interval, 310% for the 4-day interval, 550% for the 7-day interval, etc. The infinity score for 150% learning with the 28-day interval was due to the zero record for 100% learning.

From Tables IV, V, VI, and VII we may conclude that

(1) as the degree of learning was increased from 100% to 150%, the corresponding increase in retention for the one-day interval was approximately the same, and that this ratio increased rapidly as the length of the interval between learning and recall was extended;

(2) as the degree of learning was increased from 150% to 200%, (or by an additional $33\frac{1}{3}\%$), the corresponding increase in retention was usually less, and this proportion did not vary consistently with the length of the interval.

Our results thus directly contradict those of Luh. This divergency of results may be due to the differences in the conditions,—difference in material, method of measurement

and length of the interval employed. Our results suggest that the third factor may be partly responsible.

A certain degree of overlearning, at least 50%, is highly economical from the standpoint of retention for intervals of 2 to 28 days, and the larger the interval the greater is the economy. Further increases of overlearning, however, proved to be uneconomical for most intervals.

(Manuscript received June 20, 1928)

IDENTIFICATION OF MONOCULAR FUNCTIONS

BY ERNST THELIN AND ESTHER ROYAL ALTMAN

University of Cincinnati

The problem of ocular differences of sensation is not new. Previous studies reveal two points of emphasis, the one dealing with the identification of the eye involved in monocular vision and the other examining monocular differences of localization.

Among those who have approached the first problem may be mentioned Helmholtz, von Kries, Bourdon, Brückner, von Brücke, Heine and Franz.

Helmholtz, a pioneer in this field, concluded that—as regards the reference of a visual quality to the eye stimulated—"we cannot be certain about it, or at least not perfectly certain, and our judgment will depend on secondary considerations; for we cannot decipher anything from our sensations except those interpretations we have learned to make by oft-repeated observations."[1] Von Kries, investigating binocular discrimination of depth, decided that there was some discrimination between the impressions in the two eyes; "but whether this discrimination is similar to our being able to tell whether we touch an object with our right hand or with the left hand, that is a different question. The similarity between the two cases would be perfect provided that whenever a luminous stimulus acted on only one eye, the observer could tell which eye was affected."[2]

In an investigation in which both eyes were at first illuminated and then one covered, Bourdon[3] concluded that a phenomenon associated with the non-seeing eye served as a clue. This phenomenon, a kind of shadow which appeared on the same side as the eye whose vision was cut off, Bourdon called an objective phenomenon which "in nearly all cases makes a correct judgment possible as to which eye sees." With a different technique, in which the observation of the point of light was cut off from one eye from the beginning, a correct judgment was found to be "nearly always possible because of a special sensation of facility in the seeing eye, and . . . an *Abblendungsgefühl* in the non-seeing eye." Brückner and von Brücke[4] studied this *Abblendungsgefühl* of Bourdon with the aid of drugs which affected the size of the pupils and the accommodation of the eyes, and concluded that this feeling is influenced by the apparent brightness and the unequal sharpness of the images of the two eyes.

[1] H. von Helmholtz, *Handbuch der Physiologischen Optik* (from 3d German edition, Optical Society of America, J. P. C. Southall, ed.), 1925, 3, 458.

[2] J. von Kries, *ibid.*, pp. 491–492.

[3] B. Bourdon, Sur la distinction des sensations des deux yeux, *L'Année psychol.*, 1902, 43–47.

[4] A. Brückner & E. Th. von Brücke, Zur Frage der Unterscheidbarkeit rechts- und linksäugiger Gesichtseindrücke. *Pflügers Arch. f. d. ges. Physiol.*, 1902, 90, 290–302; Nochmals zur Frage der Unterscheidbarkeit rechts- und linksäugiger Eindrücke, *ibid.*, 1905, 107, 263–289.

Working with a luminous point which he caused to flash out in a dark room in such a manner that it was visible only to one eye at each exposure Heine [5] concluded that "in certain cases it is possible indeed to distinguish between the impressions in one eye or the other." On the other hand, Franz [6] declared, when working with after images, that "it is impossible to tell (by ordinary inspection) in which eye a sensation is."

Quite different from all the above was the approach of Witasek, Hillebrand and von Sterneck. They were only incidentally interested in the ability to determine to which eye the stimulus is applied. They examined instead the monocular difference of localization.

Witasek,[7] using as a fixation-point a black mark on a field of milk-white glass, a pair of blackened tubes through which the black mark was observed, and screens by means of which the vision of either eye could be intercepted, established the fact that when the two eyes look successively at a single fixation mark (screening first one eye and then the other) this point does not appear to lie in the same direction in the successive observations. This Witasek called monocular difference of localization. He attributed it, at least in part, to the orientation of the eye-ball.

Both Hillebrand [8] and von Sterneck [9] confirmed Witasek's results. While Hillebrand minimized the directional phase of the experience, his explanation, heterophoric deflection, was in agreement with Witasek's to the extent of being physiological. On the other hand, von Sterneck rejected the explanations of both Witasek and Hillebrand and advanced a psychological theory. He considered the phenomenon an illusion, precipitated by the unusual nature of the situation involved in monocular vision.

These contributions emphasize the significance of a specific factor which must be taken into consideration in any investigation of ocular identification from the stimulation of one eye alone. They appear to leave certain questions unanswered. Assuming that the ocular reference is real, to what extent does it occur among observers? What is its degree of constancy in the individual? Is it a function of experience? And are there individual peculiarities of vision which may influence the nature of the visual perception? To these questions answers were sought in the present investigation.

[5] Heine, Differenciation des perceptions de l'oeil droit et de l'oeil gauche pour la vision de l'oeil, *Ann. d'ocul.*, 1903, 128, 143 f.

[6] S. I. Franz, On after images, *Psychol. Rev. Monog. Suppl.*, 1899, 3, (no. 12), 47.

[7] St. Witasek, Zur Lehre von der Lokalization im Sehraum, *Zsch. f. Psychol.*, 1906, 50, 161–218; Lokalizationsdifferenz und latente Gleichgewichtsstörung, *ibid.*, 1909, 53, 61–96.

[8] F. Hillebrand, Zur Frage der monokularen Lokalizationdifferenz, *ibid.*, 1910, 57, 293–316.

[9] R. von Sterneck, Über wahre und scheinbare monokulare Sehrichtungen, *ibid.*, 1910, 55, 300–332.

The Experiments

Apparatus and Method of Procedure. A 2-cp electric light, fed by a storage battery, was enclosed in a box and placed in a dark room. The opening ($\frac{1}{8}$-in. diam.) in the face of the box through which the light was seen was covered with several layers of tissue paper to prevent the light filament from being visible.

The intensity used was as great as possible without illuminating the room. The light was 11 feet from the eyes of the subject. At this distance the right and left shifts in localization of the light in the field of vision with monocular exposures were found to be negligible. Two movable shutters for intercepting the line of vision of either eye were adjusted at a distance of 1 foot from the eyes. A head-rest was used.

The instructions given were to keep both eyes open at all times and to report when the light was flashed on whether it was seen with both eyes or with only one; and, if seen with one, whether with the right or the left eye. The interval between successive presentations was sufficiently long to remove any sustained right-left positional relationship which may have persisted; but it did aggravate an observed upward or downward shift in place of the light in the field. The order in which the lights were presented was varied from time to time to counteract any tendency on the part of the subject to memorize it. 100 reactions were secured each day; 25 with right eye exposed to light, 25 with left eye and 50 with both eyes stimulated. Each S served four days (400 observations). A total of 8400 observations were secured from twenty-one Ss.

All Ss were kept ignorant of the nature of the apparatus and the method of procedure. To twelve of them no information was given as to the accuracy or inaccuracy of their reports. The other nine were informed with every inaccurate observation what the correct report would have been. These corrections represented a form of aid which is treated in this paper as tuition.

Results

The results are summed up in the four accompanying tables, in which the daily records are given for each S showing the (percentage) frequency with which the light was reported as being seen with the left eye, with both eyes or with the right, the frequency of the correct report, individual constancy or variability of response, susceptibility to training, and right-left differences. The subjects are classified into four groups; (1) those who showed discriminative ability throughout the experiment, (2) low initial discrimination and improvement without tuition, (3) low initial discrimination and improvement under tuition, and (4) no discrimination and no improvement.

Universality of discrimination. The eight subjects whose

records appear in Table I were relatively accurate. Of these the first five had done a great deal of work with the microscope and four of them were daily using the microscope in their

TABLE I

SUBJECTS SHOWING DISCRIMINATION THROUGHOUT THE EXPERIMENT (PERCENTAGE FREQUENCIES)

		EYES STIMULATED								
		LEFT			RIGHT			BOTH		
	Referred to	Left	Both	Right	Left	Both	Right	Left	Both	Right
Subj. Bu Day	1	100			4		96		98	2
	2	100					100		100	
	3	100					100		100	
	4	100					100		100	
Gr	1	80	4	16	8	8	84	18	70	12
	2	100					100		100	
	3	100					100		100	
	4	100					100		100	
L	1	92		8	24	16	60	28	44	28
	2	92	8		32	4	64	24	64	12
	3	96		4		8	92	8	86	06
	4	100					100		100	
R	1	100				4	96		70	30
	2	84	4	12		12	88	4	66	30
	3	92	4	4		4	96	2	94	4
	4	100				4	96	2	94	4
St	1	100			8		92		96	4
	2	100					100		98	2
	3	100					100		100	
	4	100					100	4	96	
B	1	92		8			100		94	6
	2	88	8	4			100		100	
	3	100					100		100	
	4	100					100		100	
G	1	96	4				100		96	4
	2	100					100		100	
	3	100					100		100	
	4	100					100		100	
Mn	1	100			4		96		100	
	2	100					100		100	
	3	100					100		100	
	4	100					100		100	

work at the time. This experience may possibly have been a factor in the ability to identify ocular excitations under the conditions of this experiment; although the other three (untrained) subjects were just as accurate.

K and S, who showed improvement without tuition (Table II), were able to discriminate fairly accurately when the light was shown to the left eye or to the right, but showed less accuracy when the light was exposed to both.

TABLE II

SUBJECTS OF LOW INITIAL DISCRIMINATION WITH IMPROVEMENT WITHOUT TUITION (PERCENTAGE FREQUENCIES)

		Eyes Stimulated								
		LEFT			RIGHT			BOTH		
	Referred to	Left	Both	Right	Left	Both	Right	Left	Both	Right
Subj. K	Day 1	48	8	44	40	12	48	36		64
	2	72	4	24	40	4	56	48		52
	3	60	20	20	28	4	68	28	22	50
	4	88	4	8	12	4	84	44	6	50
S	1	52	12	36	44	16	40	26	22	52
	2	48	24	28	12	24	64	26	32	42
	3	52	8	40	28	12	60	44	36	20
	4	84		16	12	16	72	50	18	32

The subjects of low initial discrimination who improved under tuition (Table III) show a high degree of accuracy at the end. In only one case (Br) did the correct responses fall below chance during the entire experiment, and that when the light was shown to both eyes.

The records of those subjects who did not discriminate throughout the observations are given in Table IV. Two of these (C and M), serving without tuition, declared that they could not tell with which eye they were seeing the light and that most of their responses were guesses. Their records show in general a higher degree of accuracy when the light was thrown in both eyes than when the light was presented to either the left or the right alone. In the case of A, however, tuition was employed. In spite of that she did not acquire the ability to discover the eye employed during four days as subject. Her record is characterized by the frequency with which the light was reported as seen by the right eye, irrespective of the nature of the stimulation, a condition which may have been due to an unequal acuteness of the eyes.

Our results show, then, that all but 3 of the 21 subjects were able to refer the light to the eye actually stimulated.

Of these 18, 15 were able to discriminate under all conditions, while three (K, S and Br) correctly distinguished the left and right eyes but were not accurate when both eyes were stimulated.

TABLE III

SUBJECTS OF LOW INITIAL DISCRIMINATION WITH IMPROVEMENT UNDER TUITION (PERCENTAGE FREQUENCIES)

		Eyes Stimulated								
		LEFT			RIGHT			BOTH		
	Referred to	Left	Both	Right	Left	Both	Right	Left	Both	Right
Subj. An	Day 1	84	12	4	12		88	44	30	26
	2	96	4				96	22	60	18
	3	100					100	6	90	4
	4	100					100	4	92	4
Br	1	40	56	4	56	16	28	18	4	78
	2	48	12	40	28	12	60	62	16	22
	3	52	8	40	24	36	40	32	28	40
	4	60	24	16	16	4	80	36	40	24
Cs	1	12	68	20	4	52	44	4	72	24
	2	4	96		8	80	12	2	94	04
	3	52	16	32	8	20	72	10	34	56
	4	76	4	20	28		72	4	66	30
Gu	1	36	8	56	28	24	48	12	52	36
	2	56	8	36	36	16	48	4	86	10
	3	88	12		4	20	76		96	4
	4	80	16	4	12	20	68	4	96	
H	1	92		8	12	12	76	16	64	20
	2	76	16	8	20	8	72	8	78	14
	3	84	8	8	8		92	4	90	6
	4	88		12	12	12	76	4	92	4
Ku	1	36	24	40	36	16	48	8	72	20
	2	52	16	32	12	4	84		90	10
	3	76	4	20			100		96	4
	4	96		4	4	4	92	8	92	
P	1	60	24	16	12	12	76	12	44	44
	2	44	24	32	20	8	72	16	56	28
	3	64	8	28	28	4	68	6	92	2
	4	100				4	96		96	4
T	1	64	24	12	20	20	60	40	24	36
	2	80	20		12	12	76	10	84	06
	3	80	16	4	4	16	80	36	50	14
	4	100			4	4	92		100	

Constancy of accurate discrimination. Of the subjects who possessed a high degree of accuracy throughout (cf. Table I), 4 showed almost complete accuracy.

A slight variation occurs in the record for subject Gr when the light was exposed to both eyes. This may have been due to incomplete dark-adaptation since the wrong responses were made early in the first day. The same explanation might be offered for Subject L, who explained that on bright days his eyes were affected and that no amount of dark-adaptation entirely relieved that condition. The experimenter did not know of that condition until the end of the experiment. The variations occurring on the second day for Subject R might be attributed to fatigue, since the subject had studied the night before until a late hour for a final examination.

TABLE IV

EYES STIMULATED

		LEFT			RIGHT			BOTH		
Referred to		Left	Both	Right	Left	Both	Right	Left	Both	Right
Subj. C	Day 1		96	4		60	40		46	54
	2	8	72	20	8	48	44	12	44	44
	3	20	60	20	16	56	28	10	50	40
	4	12	48	40		60	40	8	50	42
M	1	40	40	20	4	28	68	8	70	22
	2	8	88	4	4	44	52	2	86	12
	3	4	96			56	44		100	
	4	12	72	16	4	52	44		76	24
A	1	16	32	52	28	20	52	10	44	46
	2		32	68		28	72		34	66
	3		32	68		24	76		34	66
	4		64	36		60	40		60	40

After the second day relative constancy prevailed with most of those subjects who acquired discriminative ability through tuition (cf. Table III).

The variability of responses of the first and second days was probably due to an absence of discriminative ability at that time, while the constancy of the last two days may be attributed to the result of training.

The two subjects of the second group (K and S) evidenced marked variability of responses, most pronounced when the light was directed to both eyes.

The three subjects who showed no ability to identify the eye stimulated (cf. Table IV) displayed a marked variability of response under all conditions.

Thus the records show that constancy of response prevailed with 16 Ss, 8 almost from the beginning and 8 acquiring it through tuition. The 5 other Ss showed variability of response, a condition that might have changed to constancy under proper training.

Susceptibility to training. That the ability to identify ocular excitations can be acquired through experience was suggested by the high degree of accuracy shown by the five subjects who worked extensively with the microscope. As

their daily records show (Table I) these subjects attained complete accuracy. The influence of such practice as was inherent in the procedure of this investigation is revealed by the records of the other three Ss of that first group, as well as by the records of those of the second group.

That tuition contributes to identification seems to be borne out by the records of those aided during the experiment. Of the Ss aided, four (An, Gu, Ku and T) showed constant improvement from day to day; while four others (Br, Cs, H and P) showed greatest constancy in improvement between the second and the fourth days. In only one case, that of Subj. A (Table IV), did tuition fail to result in improvement.

The increase in accurate reference is substantiated by the reports of those Ss who did show improvement, where they expressed an increasing assurance toward the end of the experiment.

Relative ocular acuteness. During the course of the experiment the experimenter was impresssed by the greater frequency with which some Ss reported the light as being seen by the left eye or by the right, regardless of the actual conditions of excitation. Hoping to throw some light on this condition, a test for visual apprehension with the Dodge tachistoscope was given to each subject. Cards containing letters were used, four cards being exposed to the left eye, to the right eye and to both eyes.

Nine of the subjects gave a positive correlation between ability in the main experiment and range of apprehension as shown by the tachistoscopic results; ten gave negative correlation, and two no correlation. Thus the results fail to show any consistent relationship.

It may be significant, however, to note that, where the correlation is negative, the tachistoscopic records are not impressive. Thus the range method may simply have failed to discover the inequality of the strength of the eyes.

Summational effect of stimuli. The light was directed to both eyes of each subject 200 times during the course of the experiment, 80 times immediately after a left-eye stimulation, 90 times after a right-eye stimulation, 30 times following the stimulation of both eyes. A summational effect of stimuli

might here have been operative; but our results failed to show it.

Reports of the observers. The reports of the subjects who identified the seat of retinal excitation revealed a pronounced assurance of objective correctness. As regards criteria used, 14 of the 16 competent subjects reported that when the light was directed to either eye they experienced a strain in the eye excited while the exposure to both eyes was always accompanied by a sense of ease. Six of these subjects reported an obstruction before the unstimulated eye. As three expressed it, there seemed to be a "nothingness" which later became "something" because it resisted their efforts to focus on the light, a phenomenon which suggests Bourdon's description.

Summary

1. With some individuals at least the eye involved in monocular functions may be identified when outside aids are removed. Under our conditions, the identification was sometimes complete.

2. The ability to tell which eye is functioning is subject to training in some observers; and five subjects accustomed to the microscope seemed by their high accuracy in this experiment to have profited from previous training. Eight others showed susceptibility to tuition during the course of our observations. They developed from a condition of uncertainty and low discrimination to a high degree of certainty and a corresponding degree of accuracy. Nothing in the results of this experiment would indicate that all subjects might not have acquired ability under prolonged training.

3. Individual irregularities of vision or a functional inequality of the eyes may influence the accuracy of judgment, especially during a period of training.

4. Steadiness in degree of accuracy appears to be roughly proportional to degree of training. Early uncertainty gives way to positive assurance concerning the eye or eyes stimulated.

5. With light stimuli following each other in rapid succession no summational effect was discernible in our results.

(Manuscript received June 29, 1928)